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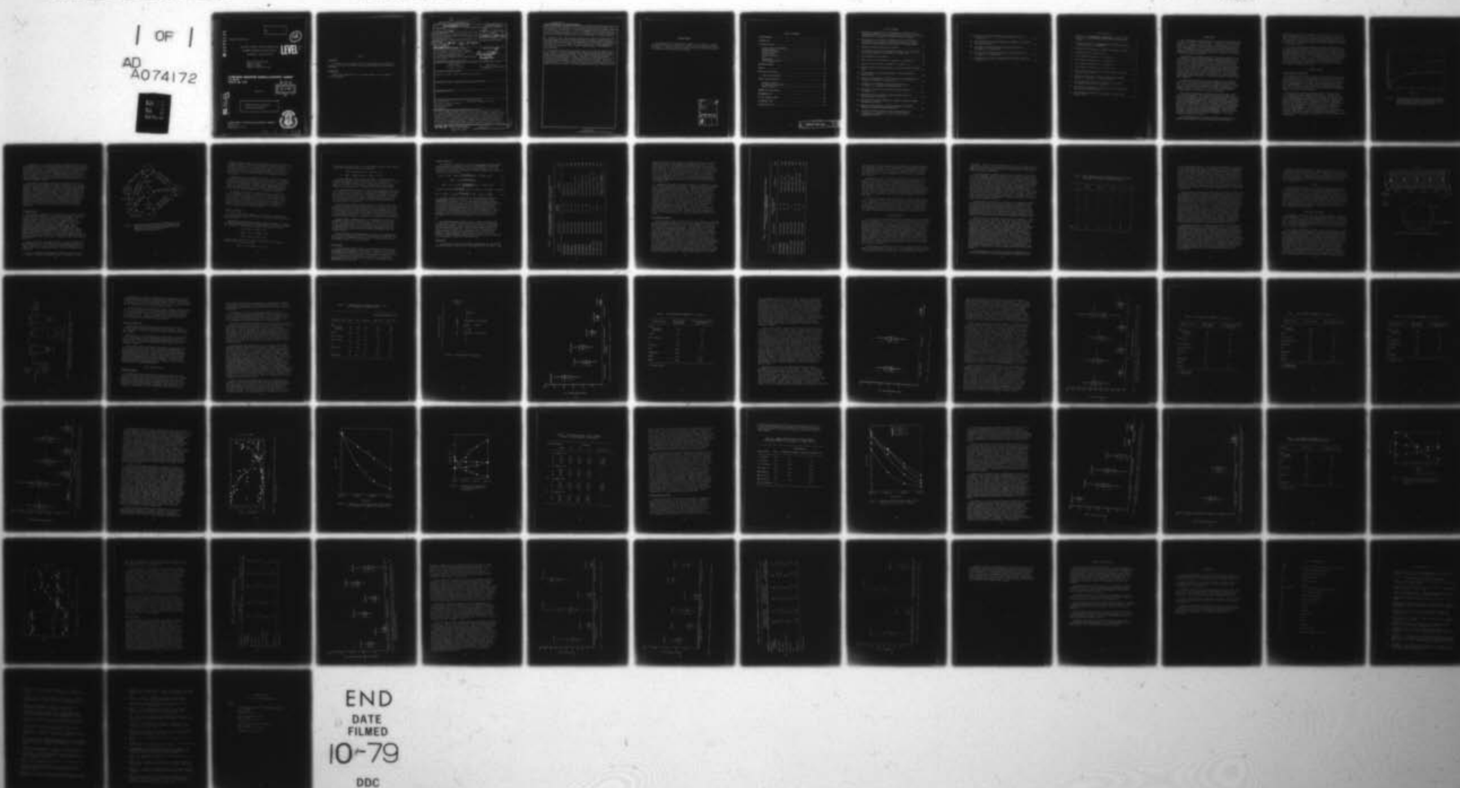

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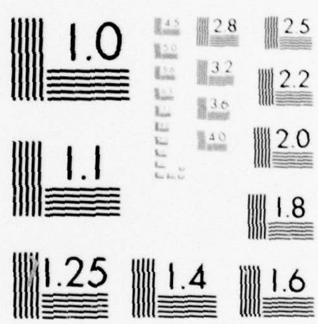

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TECHNICAL REPORT 7905

ROTATING BIOLOGICAL CONTACTOR PROCESS FOR SECONDARY TREATMENT AND NITRIFICATION FOLLOWING A TRICKLING FILTER

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Typical Army wastewater treatment plants can be upgraded to secondary standards for BOD5 by incorporation of the rotating biological contactor (RBC) process downstream of existing trickling filters. Existing trickling filter plants can also be upgraded for ammonia removal by using the RBC process for nitrification. In these studies both BOD5 removal and nitrification were affected by wastewater temperature. However, nitrification rates were more sensitive to low wastewater temperature than secondary treatment. Results indicate that chemical feed for elevated pH levels of about pH 8.0 in the RBC

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influent increases the rate of nitrification and decreases RBC surface area requirements. The decrease in required RBC surface area for secondary treatment or nitrification will result in less costly upgrades for existing trickling filter wastewater treatment facilities. Increased rates of nitrification will also result in more consistent and reliable attainment of effluent standards.

The RBC in this study received effluent from a high-rate trickling filter that performed at less than secondary effluent standards. Ammonia-nitrogen and BOD5 removal efficiencies were determined at varied hydraulic loading rates ranging from 1.5 to 4.3 gpd/sq. ft. of RBC surface area. Other parameters included the influent pH levels, organic loading rates, and suspended solids concentrations.

Performance of the RBC was evaluated over a 2-year period without temperature control, in order to determine both summer and winter efficiencies for BOD5 reduction and ammonia-nitrogen removal. RBC performance was evaluated at normal and elevated pH levels of pH 7.1 and pH 8.7 for the RBC influent (trickling filter effluent). Treatment efficiency of the trickling filter was varied to provide different levels of BOD5 in the RBC influent. Levels of suspended solids in the RBC influent were varied by having secondary settling before the RBC and having no settling between the trickling filter and the RBC.

ACKNOWLEDGMENTS

The authors wish to extend special thanks to Mr. Kenneth A. Bartgis, Engineering Technician; SSG Felix B. Legaspi, Jr., Engineering Assistant; and Charles F. Harrison, Physical Science Technician, for their technical assistance for the duration of the project.

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INTRODUCTION

Man's wastewaters contribute heavily to accelerated eutrophication problems in the nation's surface waters. Nitrogen, a growth-limiting nutrient for algae and aquatic plants, is normally present in minute quantities. However, significant amounts of nitrogenous compounds in these wastewaters result in the overfertilization of receiving water bodies. Wastewater effluent standards have, therefore, been imposed, attempting to limit the nitrogen concentration relative to that which exists at the point of discharge.

The addition of nitrogenous materials to receiving waters by way of wastewater effluents may have numerous detrimental effects on the existing biota. Ammonia-nitrogen exerts an oxygen demand thereby depleting the dissolved oxygen levels, as oxidation to nitrite and nitrate occur. Ammonia-nitrogen at levels of 0.3 mg/l is toxic to fish. Excessive algal growth is resultant of the increased concentrations of all nitrogen forms. Ammonia-nitrogen may reduce the potential for water reuse as it adversely affects chlorine disinfection, thereby creating a possible public health hazard. It is important, therefore, to study and control the biological and chemical processes which regulate the concentration of ammonia-nitrogen in treated wastewater effluents.

Nitrogen control techniques can be divided into two categories. The first is the conversion of nitrogen as ammonia to the nitrate form, while the second is the physical removal of nitrogen. The conversion of ammonia-nitrogen (NH_3-N) to nitrate-nitrogen (NO_3-N) is termed biological nitrification. Nitrification is the method of nitrogen control with which this report is concerned.

The practice of biological nitrification has only begun to blossum in the past decade. This interest in nitrification has been spurred by enactment of environmental legislation as well as increased activities of regulatory agencies. Discharge limitations have been placed for ammonia-nitrogen in the National Pollutant Discharge Elimination System (NPDES) within Public Law 92-500 (currently the Clean Water Act of 1977, Public Law 95-217). Department of the Army installations must apply for and receive discharge permits for wastewater effluents. In many cases, existing NPDES permits impose ammonia-nitrogen limitations on Army-produced wastewaters, and it is anticipated that future permits will contain comparable, if not more stringent, discharge limitations.

Existing NPDES permits also impose secondary standards for biochemical oxygen demand of less than 30 mg/l, with the limiting

concentration based on the conditions of the receiving waters. Biological treatment processes, which allow nitrification, decreases the BOD_5 level resulting from the carbonaceous and nitrogenous materials. As oxidation of carbonaceous organics and ammonia-nitrogen occur within the same process, stringent discharge requirements for both parameters are frequently obtained.

This report concerns BOD_5 reduction and NH_3-N removal through biological nitrification within a rotating biological contactor (RBC) treatment process. The RBC process was evaluated to upgrade US Army wastewater treatment facilities that currently have trickling filters. The RBC followed trickling filter treatment to provide additional BOD_5 reduction and nitrification. This treatment scheme was selected for evaluation based on several factors. It has potential utilization in existing facilities, a relatively low energy and operating cost, simplicity of operation, and flexibility with respect to expansion or upgrading of treatment facilities.

LITERATURE REVIEW

Oxygen Demand of Wastewater

The major criterion used to determine the extent of pollution for receiving waters has been the measurement of oxygen required for the stabilization of organic matter present in the system. The total amount of oxygen necessary to stabilize a waste has been referred to as the oxygen demand. The ultimate oxygen demand includes not only the amount of oxygen required to stabilize oxidizable carbonaceous materials, but also that which is required to microbially transform ammonia-nitrogen to nitrate-nitrogen.

The test used to measure the oxygen needed to oxidize organics is the biochemical oxygen demand (BOD) analysis. The BOD test is a bioassay procedure for measuring the oxygen utilized by heterotrophic bacteria during stabilization of wastewaters; however, the presence of autotrophic nitrifying organisms produce an additive effect on the observed oxygen consumption. Figure 1 illustrates the BOD curve for carbonaceous material as well as the nitrogenous phase of oxygen demand (1). For untreated domestic sewage there is little oxygen demand by nitrifying organisms for the first 8 days of stabilization. As for sewage which has received secondary treatment, conversion of ammonia to nitrate may significantly increase the BOD_5 measurement and erroneously indicate a lesser degree of treatment.

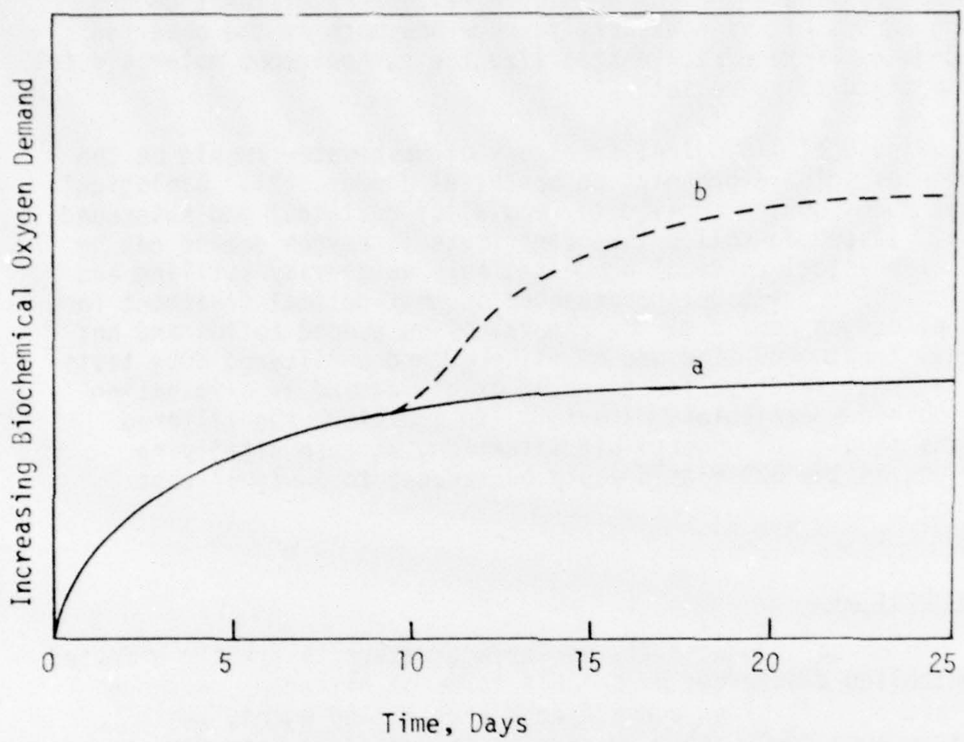

Figure 1. Biochemical Oxygen Demand is Represented with Respect to the Carbonaceous Materials Oxygen Demand (Curve a) Versus the Total Biochemical Oxygen Demand Including the Nitrogenous Materials Demand (Curve b).

In the RBC unit, as in other biological treatment processes, nitrifying organisms are interspersed among those populations which oxidize carbonaceous materials. The relative concentrations of both populations, at any specific point in the treatment train are a consequence of the nutrient supply and the amount of treatment received. Therefore, to properly assess the effect of a treated wastewater effluent on the receiving waters, it is necessary to know how much of the observed oxygen demand was required to stabilize the carbonaceous materials for which the standards were set.

The purpose of biological treatment of wastewater should be the conversion of soluble organics to bacterial biomass (2). Biological treatment needs not be applied to removal of colloidal and suspended organics. Suspended solids that contribute to oxygen demand can be removed by physical-chemical processes such as gravity settling and filtration. The practical consequence is that optimal treatment for removal of oxygen demand may be removal of suspended solids and not biological treatment. The use of filtered and unfiltered BOD_5 tests should indicate relative fractions of oxygen demand as originating from soluble or particulate material. In addition, the filtered BOD_5 tests should not undergo nitrification, because nitrifying populations in the BOD bottle would be reduced to insignificant levels (1).

Nitrogen Control

The biological productivity of surface waters is greatly affected by uncontrolled discharges of soluble forms of nitrogen. Although soluble nitrogen is often considered a fertilizing agent, its immediate effect upon receiving streams is dependent upon its oxidation state. Nitrogen exists at an oxidation state of plus 5 in the form of nitrate or at minus 3 as ammonia. In its most reduced form, ammonia decreases the dissolved oxygen level downstream from its point of discharge. The lowered dissolved oxygen concentrations may be detrimental to aquatic life. Another problem associated with ammonia is its acute toxicity to fish (3). Ammonia causes fin and tail decay as well as pathological changes in the gill structures of rainbow trout. Reportedly, ammonia-nitrogen at concentrations of 0.25 to 0.30 mg/l are lethal to fish within 14 to 21 days (3).

The oxidized form of nitrogen, nitrate, is readily available for assimilation by plant life, causing agal blooms when present in too large a quantity (1). Also, nitrate can cause methemoglobinemia in infants when nitrate contaminated water is used as a drinking water supply (4).

Figure 2 illustrates the changes in oxidation state of nitrogen as biological oxidation and reduction occur. The portion of the

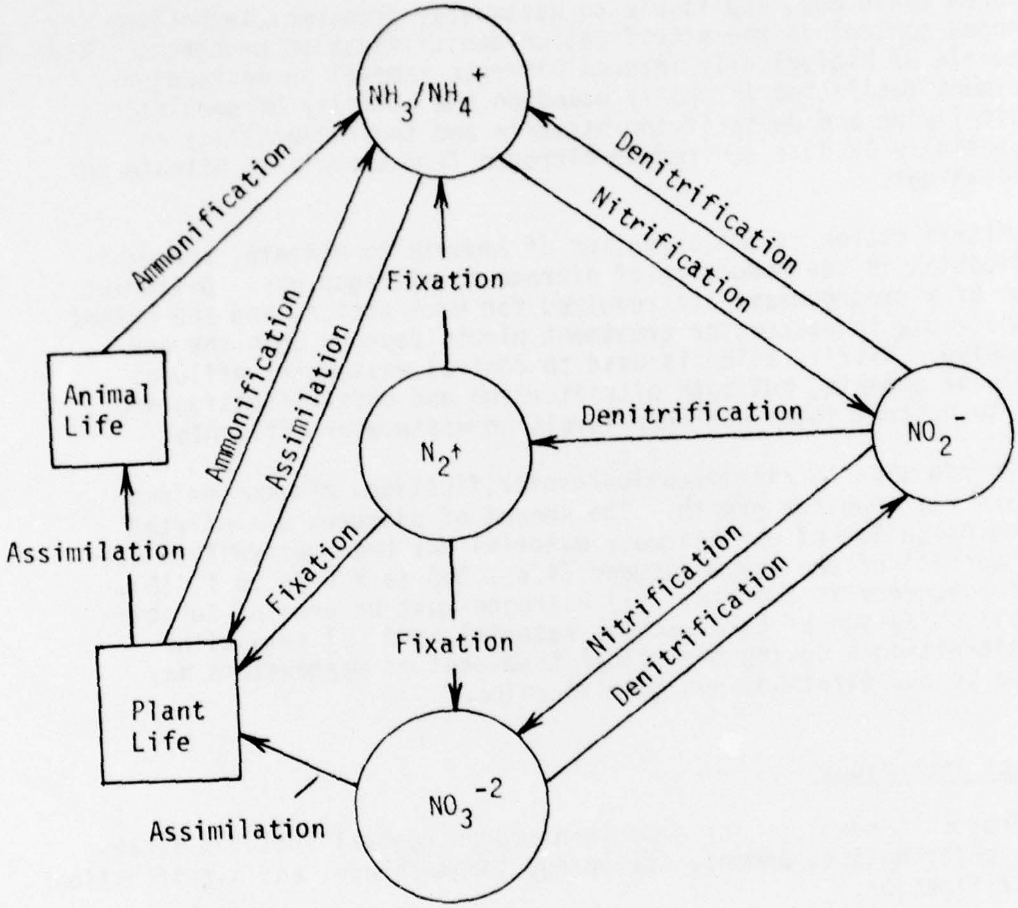

Figure 2. Nitrogen Cycle, the Portion Illustrated by Circles Shows the Significance of Biological Oxidation and Reduction on which Wastewater Treatment Processes are Based for Nitrogen Control.

nitrogen cycle most applicable to wastewater treatment technology for nitrogen control is the nitrification-denitrification processes. The principle of biologically induced nitrogen removal in wastewater treatment facilities is wholly based on the activity of populations of nitrifying and denitrifying bacteria and their capability to sequentially oxidize and reduce nitrogen from ammonia to nitrate to nitrogen gas.

Nitrification is the oxidation of ammonia to nitrate, and denitrification is the reduction of nitrate to nitrogen gas. Different types of microorganisms are required for each action, and the extent of their use in wastewater treatment plants depends upon the end objective. Nitrification is used to control wastewater effluent levels of ammonia, but both nitrification and denitrification are used to control total nitrogen levels in wastewater effluents.

In addition to nitrification/denitrification, microorganisms require nitrogen for growth. The amount of nitrogen assimilated during oxidation of carbonaceous material has been generally placed at 5 percent of the oxygen demand (i.e., BOD to N = 20 to 1) (5). The consequence is twofold: (1) nitrogen must be present for biological oxidation of carbonaceous material, and (2) removal of ammonia-nitrogen during biological treatment of wastewaters may be due to assimilation, not nitrification.

Process Technology

Process technology for ammonia-nitrogen removal includes breakpoint chlorination, ammonia stripping, ion exchange, and nitrification/denitrification.

Breakpoint chlorination occurs when a sufficient amount of chlorine is added to wastewater effluent to convert ammonia-nitrogen to nitrogen gas. Equations illustrating the conversion are given as follows:

$$NH_3 + HOCl \longrightarrow NH_2Cl + H_2O$$

$$NH_2Cl + HOCl \longrightarrow NHCl_2 + H_2O$$

$$NHCl_2 + HOCl \longrightarrow NCl_3 + H_2O$$

if free chlorine species still exist, dichloramine will be highly unstable and may react as follows:

$$NHCl_2 + H_2O \longrightarrow [NOH] + 2H^+ + 2Cl^-$$

The nitroxile radical, [NOH], is an intermediate which has been theorized to explain the observed yield of nitrogen gas.

$$NH_2Cl + [NOH] \longrightarrow N_2\uparrow + H_2O + H^+ + Cl^-$$

$$\text{or} \quad NHCl_2 + [NOH] \longrightarrow N_2\uparrow + HOCl + H^+ + Cl^-$$

As the breakpoint reactions near completion, the wastewater pH is slightly depressed due to the production of HCl. This process is highly effective for ammonia removal, but is costly and requires a large quantity of chlorine (10x the ammonia concentration), which produces numerous chlorinated organics of unknown impact on the environment.

The ammonia stripping process is based on two fundamental principles. First, the pH must be increased to a value of approximately pH 11.0 which causes almost complete conversion of ammonium ion to ammonia gas, which will exist in a less soluble state. Secondly, ammonia gas is removed from the water by escaping to the air by providing good air-water contact and agitation to increase droplet formation and reformation on stripping tower packing material.

Even though the ammonia stripping concept is based on a very simple principle, a number of operational problems exist. Because the pH has to be greatly elevated, scale formation in the tower may result. Also, as effluent and air are forced through the packing material, the effluent is cooled, thereby decreasing the ammonia removal efficiency due to increased ammonia solubility. In addition, it is necessary to consider the fate of ammonia removed with respect to its impact on the environment.

Another method of ammonia removal is accomplished by passing the wastewater through ion exchange materials. In theory, ion exchange involves the displacement of sodium, magnesium, or calcium ions from an ion exchange material such as clinoptilolite. After some period of operation, the clinoptilolite beds must be regenerated by a basic solution (usually a lime slurry) which removes the ammonia from the exchange material.

Unlike breakpoint chlorination where an inert gas is produced, the washing of the exchange material leaves a solution of ammonia which must be processed. The ammonia laden wash water is usually cycled through air-stripping towers so it can be reused.

Nitrification

The two microbial genera usually associated with nitrification are *Nitrosomonas* and *Nitrobacter*. Both genera of organisms are autotrophic nitrifying bacteria indicating that energy for growth is derived from the oxidation of inorganic nitrogen. The oxidation of ammonia to nitrate is a two step process requiring both organisms for the conversion. *Nitrosomonas* transforms ammonia to nitrite while *Nitrobacter* further oxidizes nitrite to nitrate.

Process Chemistry

The oxidation of ammonia to nitrate by *Nitrosomonas* and *Nitrobacter* requires numerous intermediate steps, many of which will affect the observed rate of ammonia removal and consequent formation of nitrate. The overall stoichiometric reactions for ammonia oxidation and bacterial synthesis are listed below.

$$NH_4^+ + 1.5\ O_2 + 2\ HCO_3^- \xrightarrow{Nitrosomonas} NO_2^- + 2\ H_2CO_3 + H_2O \quad (1)$$

$$NO_2^- + .5\ O_2 \xrightarrow{Nitrobacter} NO_3^= \quad (2)$$

$$NH_4^+ + 2\ O_2 + 2\ HCO_3^- \xrightarrow[Nitrobacter]{Nitrosomonas} NO_3^= + 2\ H_2CO_3 + H_2O \quad (3)$$

$$13\ NH_4^+ + 23\ HCO_3^- \xrightarrow{Nitrosomonas} 8\ H_2CO_3 + 10\ NO_2^- + 3\ C_5H_7NO_2 + 19\ H_2O \quad (4)$$

$$NH_4^+ + 10\ NO_2^- + 4\ H_2CO_3 \xrightarrow{Nitrobacter} 10\ NO_3^= + 3\ H_2O + C_5H_7NO_2 \quad (5)$$

It can be seen from equation (4) that as ammonia is oxidized by *Nitrosomonas* carbonate is utilized. As nitrite formation occurs carbonic acid is produced. This microbiologically induced change in the carbonate buffering system results in the destruction of alkalinity at a rate of 7.1 mg (as $CaCO_3$) per mg of ammonia oxidized (6) (7). As the nitrification process reduces the alkalinity and increases the carbonic acid concentration, the pH of the wastewater may drop as low as pH 6.0, and adversely impact the rate of nitrification. This decrease in pH can be minimized by aeration to strip CO_2 from the wastewater, or by insuring the presence of excess alkalinity (6).

pH

The reported pH optima shown in Table 1 cover a wide range, but the concensus is that as the pH decreases the rate of nitrification processes also decline. Sawyer, *et al*. (8), and Engel and Alexander (9) have reported pH optima for nitrification between 8.0 and 9.0, and 7.0 and 9.0, respectively. Painter (10) has stated that nitrification processes cease at or below pH 6.3 to 6.7. Poduska and Andrews (1) have shown that abrupt changes in pH from 7.2 to 5.8 markedly reduced the ammonia oxidation by nitrifiers while the reversal in pH restored the original nitrification rate.

Temperature

The variations of influent wastewater temperatures for Fort Detrick have been previously shown to be in the range of 10 to 26°C (40). These

TABLE 1. pH OPTIMA FOR NITROSOMONAS, NITROBACTER, ACTIVATED SLUDGE ORGANISMS, AND ATTACHED ORGANISMS AS REPORTED BY VARIOUS AUTHORS

Organism	Test Culture	Optimal pH Range	Reference	Date
Nitrosomonas	Pure Culture	8.5 - 8.8	Meyerhoff (12)	1917
Nitrobacter	Pure Culture	8.5 - 9.0	Meyerhoff (12)	1917
Nitrobacter	Pure Culture	6.5 - 9.4	Winogradsky (13)	1933
Nitrosomonas	Pure Culture	8.0 - 9.0	Hoffman and Lees (14)	1953
Nitrosomonas	Pure Culture	8.0 - 8.5	Buswell *et al*. (15)	1954
Nitrosomonas	Pure Culture	7.0 - 9.0	Engel and Alexander (9)	1958
Nitrobacter	Pure Culture	7.0 - 8.6	Boon and Laudelot (16)	1962
Nitrosomonas	Pure Culture	7.5 - 8.0	Loveless and Painter (17)	1968
Activated Sludge	Mixed Culture	8.4	Wild, Sawyer, McMahon (18)	1971
Attached Growth	Mixed Culture	7.0 - 8.2	Srna and Baggley (19)	1975
Attached Growth	Mixed Culture	8.4	Operation of Wastewater Treatment Plants MOP/11 (7)	1976

temperatures are for most purposes lower than those values reported as optimal for growth of Nitrosomonas and Nitrobacter (Table 2). The temperature data listed was mostly derived from warm liquid synthetic media cultures, not considering the practical aspects of waste treatment facilities. Careful consideration must be given to the conditions under which these temperature optima were obtained. For example, one should not expect the same temperature or pH optima from attached growth and suspended growth systems, or from mixed cultures and separate stage processes. This has not always been addressed and has, therefore, created some confusion in the literature regarding temperature effects (6).

Temperature dependence of microbial activity is important in assessing efficiency of biological treatment. Temperature influences heterotrophic and autotrophic microorganisms, thereby affecting secondary treatment and nitrification efficiencies. The nitrification rate is more temperature sensitive than the rates for organic removal (2). Nitrification rates decrease about 50 percent for each 10°C drop in wastewater temperature below about 30°C (6). For example, the nitrification rate at 10°C would be about half that of 20°C. Secondary treatment efficiency is less likely to be affected by temperature changes, probably due to microbial population diversity and other system constraints (2). Organic removal rates for fixed-film processes should decrease about 25 percent for each 10°C drop in wastewater temperature below about 30°C. For example, the rate of biological activity in a trickling filter process, at 10°C would be about 75 percent of that at 20°C. However, the actual temperature effect on a biological process is probably characteristic only of that system.

RBC Treatment Process

During the past decade the RBC process has been studied as a feasible wastewater treatment alternative to Activated Sludge and Trickling Filter process (28) (29) (30) (31) (32) (33). This interest is accountable due to the ability of the RBC process to provide nitrification as well as oxidation of carbonaceous materials. The RBC consists of a series of plastic disks of which 40 percent of the surface area is rotated through the wastewater effluent. As the disks are rotated, the entire media surface develops a culture of microbiological organisms. The organisms adhere and multiply to form a uniform growth referred to as a fixed-film. The biomass supported by the plastic media picks up a thin layer of nutrient laden water as it rotates through the wastewater. The film of water trickles over the microorganisms which remove dissolved solids and oxygen. The rotation of the media through the wastewater not only allows for aeration and mixing of the mixed liquor, but also provides sheer forces which cause sloughing of excess growth. RBC units are usually operated in series to remove organic matter with the latter stages providing nitrification. Nitrification processes do not begin

TABLE 2. TEMPERATURE OPTIMA FOR *NITROSOMONAS* AND ATTACHED ORGANISMS AS REPORTED BY VARIOUS AUTHORS

Organism	Test Culture	Optimal Temperature Range (°C)	Reference	Date
Nitrosomonas	Pure Culture	30 - 36	Buswell *et al*. (15)	1954
Nitrosomonas	Pure Culture	34 - 35	Deppe *et al*. (21)	1960
Nitrosomonas	Pure Culture	28 - 30	Laudelot *et al*. (22)	1960
Attached Growth	Mixed Culture	30	Balakrishnan (23)	1969
Attached Growth	Mixed Culture	28 - 35	Haug and McCarty (24)	1971
Attached Growth	Mixed Culture	28 - 35	Huang and Hopson (25)	1974
Attached Growth	Mixed Culture	>13	Antonie (27)	1974

until the BOD_5 and corresponding large populations of heterotrophs have been adequately reduced. The actual reason that heterotrophic organisms and autotrophic nitrifiers do not co-exist in equal quantities throughout successive RBC stages is not clearly understood, but it is known that the activities of the two populations do not occur simultaneously (18) (34) (35).

Traditionally, banks of RBC units are operated in series with the number of units depending upon the hydraulic load to be treated. The function of the first stages is to remove organic material, with subsequent stages removing ammonia (when nitrification is necessary to meet effluent standards). The degree of nutrient removal achieved has been attributed to the hydraulic loading of the system, usually expressed as the volume of wastewater applied to a square measure of surface area per day. One to 4 gpd/sq. ft. have often been used at standard loading rates for pilot plants (36) and full scale waste treatment facilities (34) (39).

The change in hydraulic load also changes the organic load as more food is introduced to the active component of the waste treatment system. It has recently been suggested that shortcomings observed in the quality of treatment by RBC units was due to excessive organic loading, while operating at less than hydraulic design capacity (34). The question of which parameter, hydraulic loading or organic loading, should be used for proper design and operation of an RBC process is yet to be decided.

RESEARCH APPROACH

In order to assess the impact of Public Law 92-500 on US Army installations, a comprehensive review of NPDES permits was conducted in early 1976 for many Army wastewater discharges. Of 78 installations reviewed, 49 had been issued NPDES permits for 64 wastewater discharges. Since Public Law 92-500 placed limitations on wastewater discharges, but did not dictate methods of obtaining limitations, the Army had alternatives of meeting stringent limitations by advanced wastewater treatment (AWT), land application of wastewater, wastewater reuse, or connection to area-wide systems. Nineteen of the 78 installations reviewed had all wastewater discharges connected to municipal area-wide systems, with 10 installations pending connection to area-wide systems. Feasibility studies for land application had been conducted at 14 installations, but pursuit of land application as a means of meeting NPDES permit limitations had ceased at most of these installations.

Of the remaining alternatives for meeting stringent discharge requirements, AWT was applicable in most cases. Of the 64 NPDES permits received, 37 required only secondary treatment while 27 contained more stringent

limitations. AWT was the only alternative in most cases. More specific data on the 27 permits containing AWT requirements are presented in Table 3. Ammonia-nitrogen removal was indicated for over one-half of those wastewaters having AWT requirements.

US Army wastewater treatment systems consist primarily of trickling filters as secondary treatment processes, a few activated sludge systems, and several extended aeration package plants. The Army has unique situations in which treatment plants are often flow underloaded due to decreases in the size of the Army population during peacetime. Also, consolidation of activities from several installations to only one installation, summer training of Researve and National Guard troops, and manuevers of troops can cause drastic seasonal changes in loadings on treatment plants. Drastic diurnal changes in loadings can be caused by civilian work forces that contribute wastes during normal working hours, but not at other times. In addition, size of Army treatment plants (0.1 to 5.0 MGD), dictate the need for simplicity of operation and maintenance. Therefore, AWT techniques applied to municipal wastewater treatment systems may not be applicable to Army treatment systems.

The RBC process was selected for evaluation for secondary treatment and nitrification following a trickling filter to provide technology applicable to upgrading Army wastewater treatment facilities. The choice of this treatment scheme considered the relatively low energy and operating costs of the RBC process, simplicity of operation, and flexibility with respect to the upgrading of existing treatment plants. Therefore, RBC technology and state-of-the-art BOD_5 reduction and biological nitrification processes have been reviewed and presented herein.

The RBC process was developed during the past two decades. In the last few years, the RBC process has been chosen over trickling filter and activated sludge systems in some designs. Reportedly, the RBC process allows for a longer and more intense contact time than the trickling filter process, thereby increasing BOD_5 removal. Continuous sloughing of biomass is a feature of an RBC process, whereas excess growth on a trikling filter can cause pondings. A high degree of treatment within an RBC can be achieved by proper design of aeration capabilities and effluent retention without unnecessary recycling of effluent to maintain minimum wetting rates. The RBC process is less likely to be affected by organic shock loads or a hydraulic surge as would the activated sludge process, which relies on sludge recycling to maintain the proper food-to-microorganisms ratio. Lastly, because of the high density of the biological solids in the RBC process, purportedly higher flow rates can be used in the secondary clarifier, yet maintain a comparable or thicker sludge than the activated sludge process.

In the RBC process, as with other biological treatment processes, nitrifying organisms are interspersed among those populations which

TABLE 3. NPDES PERMITS REQUIRING ADVANCED WASTEWATER TREATMENT AT US ARMY INSTALLATIONS (64 PERMITS REVIEWED)

	P	NH_3-N	Total N	BOD	SS	Total
	2	-	-	-	-	2
	-	2	-	-	-	2
	4	4	4	4	4	4
	1	1	-	1	1	1
	-	5	-	5	-	5
	2	2	-	2	-	2
	2	-	-	2	2	2
	-	1	-	1	1	1
	-	-	-	8	8	8
Total	11	15	4	23	16	27

utilize carbonaceous material. As explained previously, it is necessary to have adequate degradation of carbonaceous material (BOD_5 reduction) before nitrification can occur to any appreciable extent. A number of factors which affect BOD_5 reduction also affect the systems ability to provide a nitrified effluent. Some of these factors include hydraulic loading, organic loading, shock loading, dissolved oxygen, temperature, and pH. For example, increases in the organic loading requires more RBC surface area for BOD_5 reduction and less surface area is therefore available for nitrification. The degree of nitrification will be proportionally reduced. Reduction in nitrifier activity may be due to the presence of oxidizable carbonaceous material, depressed dissolved oxygen concentrations resultant of the increased organic loading, or a combination of both.

Other variables influencing effluent BOD_5 and ammonia concentrations are temperature and pH. The effect of temperature on microbial activity and consequent substrate and nutrient removal is blatantly visible, but more surreptitious is the effect of temperature on the dissolved oxygen concentration in the wastewater, which in turn affects substrate and nutrient utilization. For example, during summer months the temperature favors high rates of microbial activity, but the dissolved oxygen transfer into the wastewater is poor. As a result, lower dissolved oxygen levels may limit microbial activity. During winter months the lower temperature favors oxygen transfer, but microbial activity decreases. Since temperature is one agent causing poor performance of treatment plants in both summer and winter, the rates of oxygen transfer and microbial activity must be considered with respect to each parameter. Microbial activity is also affected by pH. However, the intertwined effects of pH, temperature, dissolved oxygen, organic loading, and hydraulic loading can create chaos while attempting to determine the optimal operating parameters for wastewater treatment facilities.

Carbonaceous material and ammonia-nitrogen are two major components removed from wastewater by the RBC treatment process. This project investigated both parameters with emphasis on the ammonia-nitrogen concentration in the final effluent. Removal efficiencies across the RBC were compared for wastewater which had the RBC influent pH elevated to 8.7 by the addition of lime, and for wastewater which received no pH adjustment. In each case the wastewater had been previously treated by a high-rate trickling filter before entering the RBC unit. The trickling filter was added to simulate conditions of an Army upgrade scenario, in which an existing trickling filter plant is upgraded by adding an RBC unit to the trickling filter effluent. This trickling filter treatment was expected to provide less than secondary treatment conditions, so that the RBC process would provide additional BOD_5 removal plus nitrification.

Hydraulic loading rates were the primary consideration in RBC process efficiency for nitrification. Organic loading was a second consideration for nitrification efficiency. Intermediate settling between the trickling filter and RBC process was evaluated for its effect on RBC treatment performance. Target levels for RBC effluent concentrations were 10 mg/l for BOD_5 and 2.0 mg/l for ammonia-nitrogen at the lower loading conditions.

PURPOSE

The purpose of this study was to evaluate performance of the RBC for BOD_5 reduction and ammonia-nitrogen removal where the RBC followed a trickling filter. The RBC in this study received effluent from a high-rate trickling filter that performed at less than secondary effluent standards (i.e., trickling filter secondary effluent BOD5 was routinely greater than 30 mg/l). Ammonia-nitrogen and BOD_5 removal efficiencies across the RBC were determined at varied hydraulic loading rates ranging from 1.5 to 4.3 gpd/sq.ft. of RBC surface area. Other parameters which were varied included the influent pH levels, organic loading rates, and suspended solids concentrations. Performance was evaluated during both summer and winter conditions.

MATERIALS AND METHODS

Performance of an RBC was evaluated for BOD_5 reduction and ammonia-nitrogen removal at the pilot-scale where the RBC followed a trickling filter. The RBC consisted of four compartments in series. The 0.5 meter plastic disks provided 250 sq.ft. of surface area for microbial attachment. The disks are rotated through liquor at 13 rpm with 40 percent of the fixed-film submerged at any point. A schematic of the pilot RBC process is shown in Figure 3.

Pilot studies used domestic wastewater from the Fort Detrick housing area. The wastewater was shredded by a grinder pump and pumped into a 250 gallon equalization tank which was periodically replenished through a float level switch control. This enabled a relatively constant flow of partially settled wastewater to be pumped into the primary clarifier. The wastewater flowed by gravity through the primary clarifier and was then pumped to a high-rate trickling filter. The trickling filter contained a 2-inch irregular stone media with effective media depth of 4 ft. and 2.25 sq. ft. of filter surface. Effluent was collected at the bottom of the filter in a wet well and pumped to the secondary clarifier. This pretreatment scheme is shown in Figure 4 and was used to simulate an existing trickling filter plant. The RBC followed trickling filter treatment and was used as an upgrading technique for additional BOD_5 reduction and nitrification (ammonia-nitrogen removal).

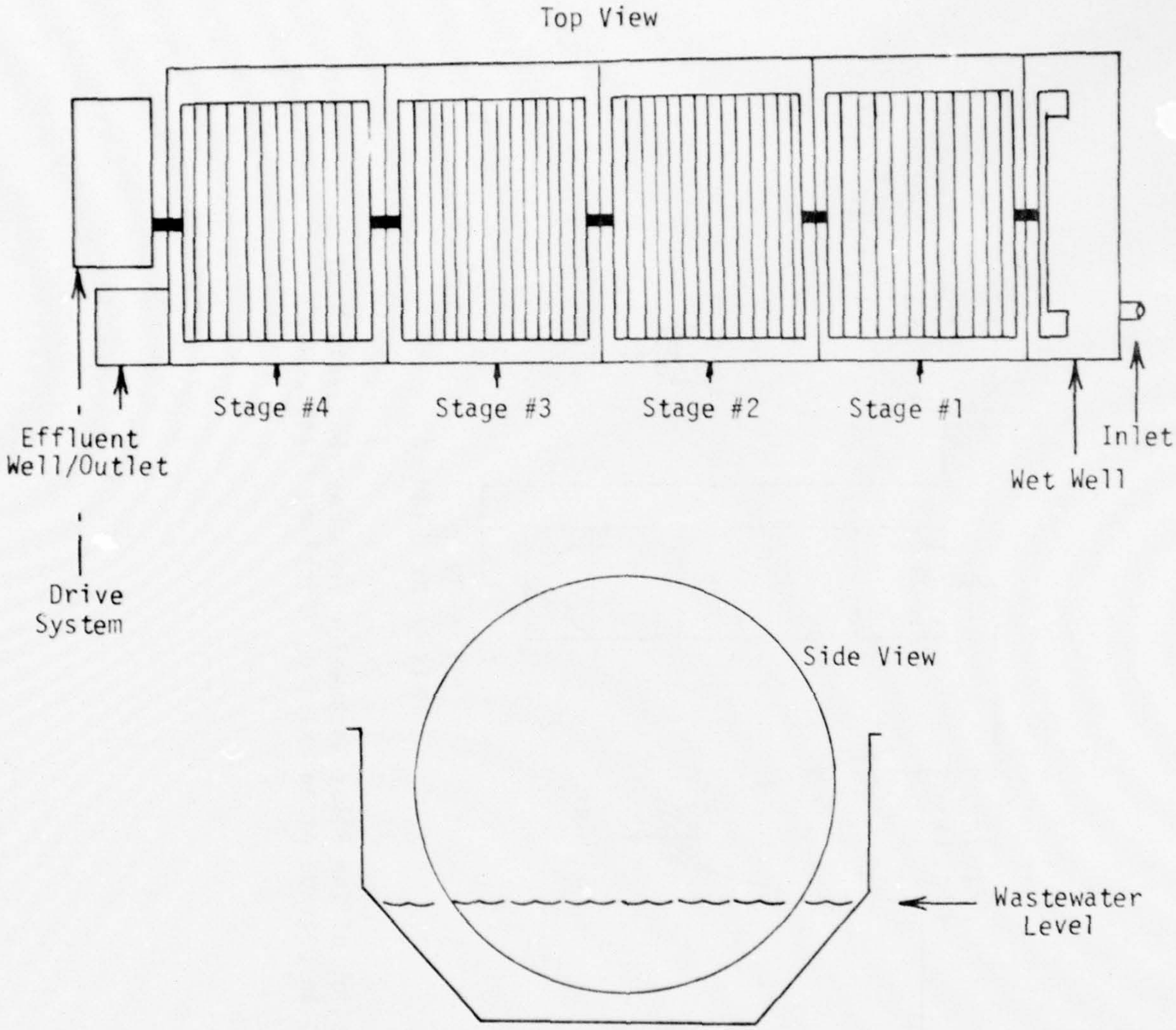

Figure 3. Diagram of Rotating Biological Contactor.

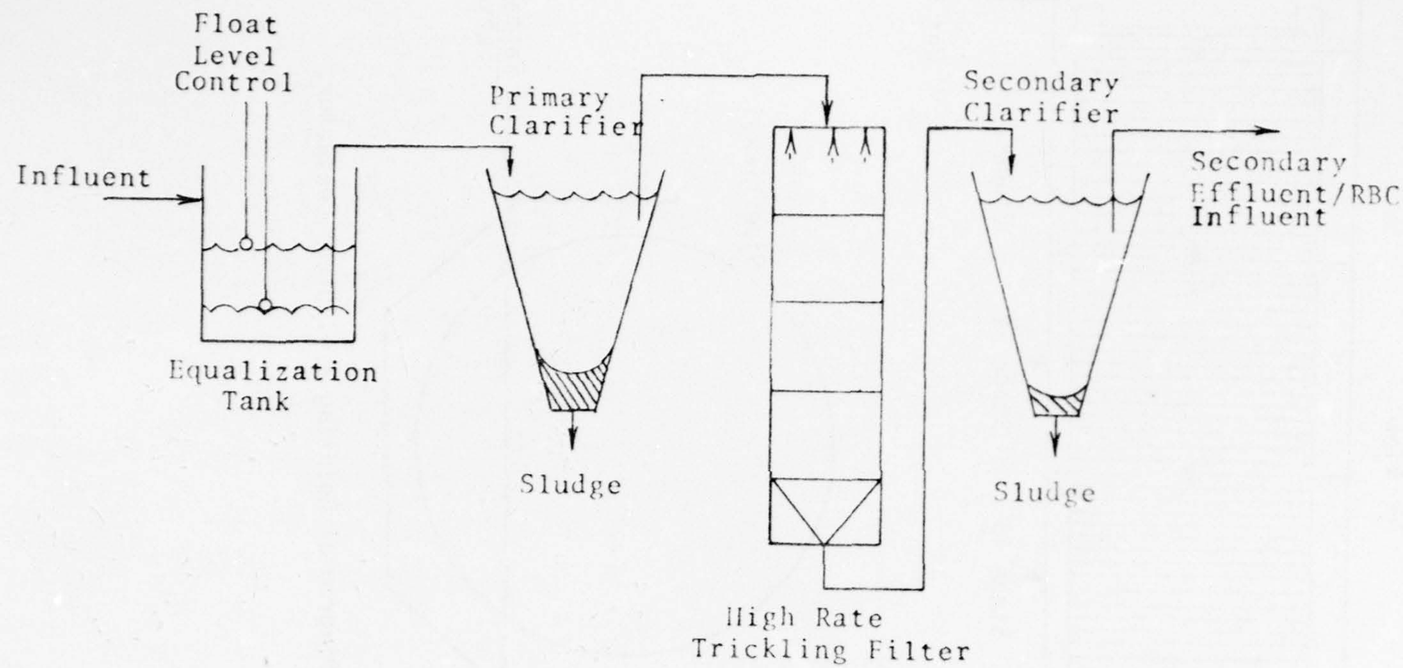

Figure 4. Illustration of the Pilot Wastewater Treatment Facility Used to Simulate an Upgrade of an Existing Trickling Filter.

Performance of the RBC was evaluated over a two-year period without temperature control in order to determine both summer and winter efficiencies for BOD_5 reduction and ammonia-nitrogen removal. RBC performance was evaluated at normal and elevated pH levels of pH 7.1 and pH 8.7 for the RBC influent (trickling filter secondary effluent).

The RBC influent flow was varied to provide hydraulic loading ranging from 1.5 to 4.3 gpd/sq. ft. of RBC surface area. Treatment efficiency of the trickling filter was varied to provide different levels of BOD_5 in the RBC influent. Levels of suspended solids in the RBC influent were varied by having secondary settling before the RBC and having no settling between the trickling filter and the RBC.

Sampling and Analyses

Sample points included 24-hour composites of primary influent, trickling filter effluent (RBC influent) and RBC effluent. Analyses of test parameters in the four stages of the RBC unit were determined from grab samples.

Measurements of flow, temperature, dissolved oxygen, pH, suspended solids, total organic carbon, and ammonia-nitrogen were made daily. Alkalinity and chemical oxygen demand (COD) measurements were made four times per week. Biochemical oxygen demand (BOD_5) analyses were performed twice weekly.

Total organic carbon measurements were made on a Beckman Model 915 Total Organic Carbon Analyzer. Ammonia-nitrogen concentrations were measured with an Orion specific ion electrode. Dissolved oxygen and BOD_5 determinations were made using a Delta Scientific Model 2110 Dissolved Oxygen Meter and probe. Chemical oxygen demand, total Kjeldahl nitrogen, and phosphorous analyses were made using a Technicon Auto Analyzer II system according to Technicon methods. Filtered samples were filtered through fiberglass filters. All other analyses were performed according to Standard Methods (36).

RESULTS AND DISCUSSION

Hydraulic Loading

The RBC was initially evaluated for secondary treatment and nitrification following a high-rate trickling filter during the fall, winter, and spring of 1976-1977 at hydraulic loadings of 1.5, 2.0, 3.0, and 4.0 gpd/sq. ft. of RBC surface area. Secondary treatment efficiency was evaluated using filtered and unfiltered BOD_5, and filtered TOC. Nitrification efficiency was evaluated using NH_3-N, TKN, NO_2-N/NO_3-N, and alkalinity. Suspended solids, pH, temperature, and dissolved oxygen

levels within the RBC stages were monitored. Sample points included raw wastewater, trickling filter effluent and RBC effluent. Limited sampling was conducted within stages of the RBC to evaluate progression of treatment.

Characteristics of the raw degritted wastewater are shown in Table 4. Wastewater parameters were found to remain relatively constant on both a diurnal basis and from day to day. Confidence intervals in Table 4 are indicative of the relatively consistent strength of the wastewater, which was probably due to flow equalization.

Within this report box-and-whisker plots are used in the evaluation of results of pilot studies, as shown in the figure that follows (Figure 5). A detailed explanation of box-and-whisker plots is contained in Reference 37. The box represents the central quartiles of data. The lower edge of the box corresponds to the bottom quarter (25 percent) of data points, while the upper edge corresponds to the upper quarter (75 percent). The horizontal line across and extending out of the box corresponds to the median value (50 percentile). The whisker is the vertical line at each end of the box, and is drawn the same length as the box, as a visual aid. Data points are plotted to the left of the box-and-whiskers.

Figure 6 shows BOD_5 removal across the trickling filter and RBC treatment processes, where the RBC received 1.5 gpd/sq. ft. of flow from the trickling filter. The trickling filter treated approximately 1000 gpd, and only part of the secondary effluent was pumped to the RBC. Domestic wastewater was treated to less than secondary standards by the high-rate trickling filter, as indicated by the filtered BOD_5 level of 50 mg/l for trickling filter secondary effluent. The RBC provided additional treatment to better than secondary standards as shown by the RBC secondary effluent level of 9 mg/l for filtered BOD_5. Secondary treatment performance of the RBC is shown by data in Table 5 in which the RBC removed 20 mg/l of TOC. Table 5 also shows environmental conditions of the study at 1.5 gpd/sq. ft. The wastewater temperature averaged 13.4°C during this period in January and February of 1977, and the median pH for RBC influent was 8.6. Natural (biological) recarbonation and nitrification within the RBC process depressed the pH to about 7.5 in the RBC secondary effluent. It can be concluded from Figure 6 that an existing trickling filter can be upgraded to secondary standards by use of an RBC process.

Figure 6 also shows unfiltered BOD_5 levels at various points of treatment. Careful consideration should be used in evaluating treatment efficiency of the biological processes based on unfiltered BOD_5. The oxygen demand of suspended solids makes unfiltered BOD_5 levels higher than filtered BOD_5 for raw wastewater and trickling filter secondary effluent. For highly treated RBC secondary effluent, nitrification could add to the oxygen demand of suspended solids to make

TABLE 4. CHARACTERIZATION OF SEWAGE INFLUENT TO THE PILOT WASTEWATER TREATMENT FACILITY

				Confidence Intervals (95%)	
Parameter (mg/l)	Number	Mean	Variance	Lower Limit	Upper Limit
BOD_5					
Filtered	38	113	38	101	125
Unfiltered	35	212	42	199	225
NH_3-N	100	17.0	5.7	12.2	21.7
TOC, Filtered	72	73	15	66	81
COD, Filtered	80	163	83	145	181
SS	76	107	40	94	120
Alkalinity	59	148	37	136	160
pH	99	7.2	0.3	6.2	8.2
Temperature	94	18.1	2.7	14.8	21.4

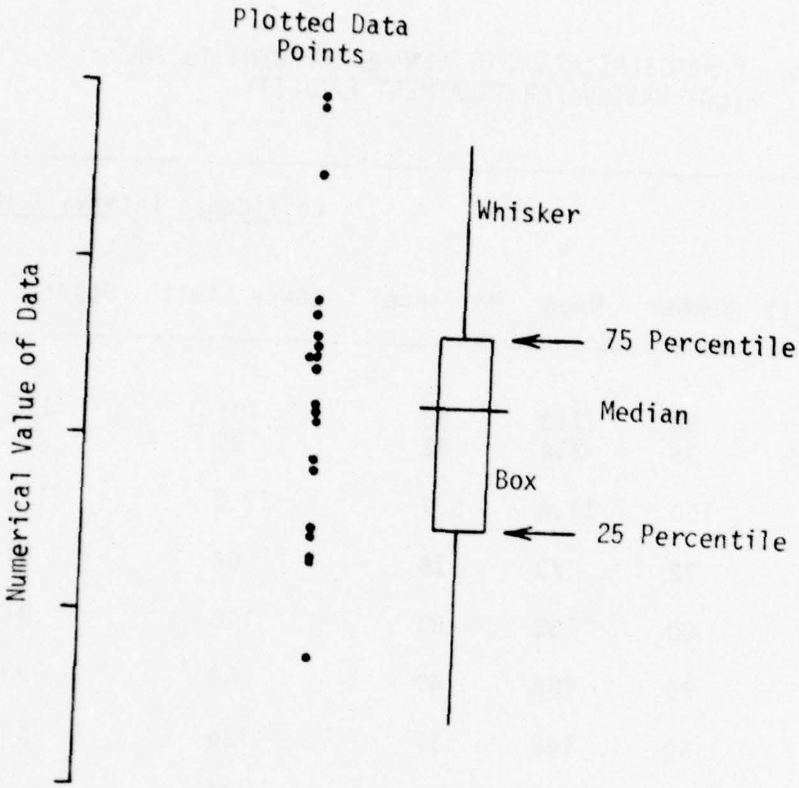

Figure 5. Box-and-Whisker Illustration.

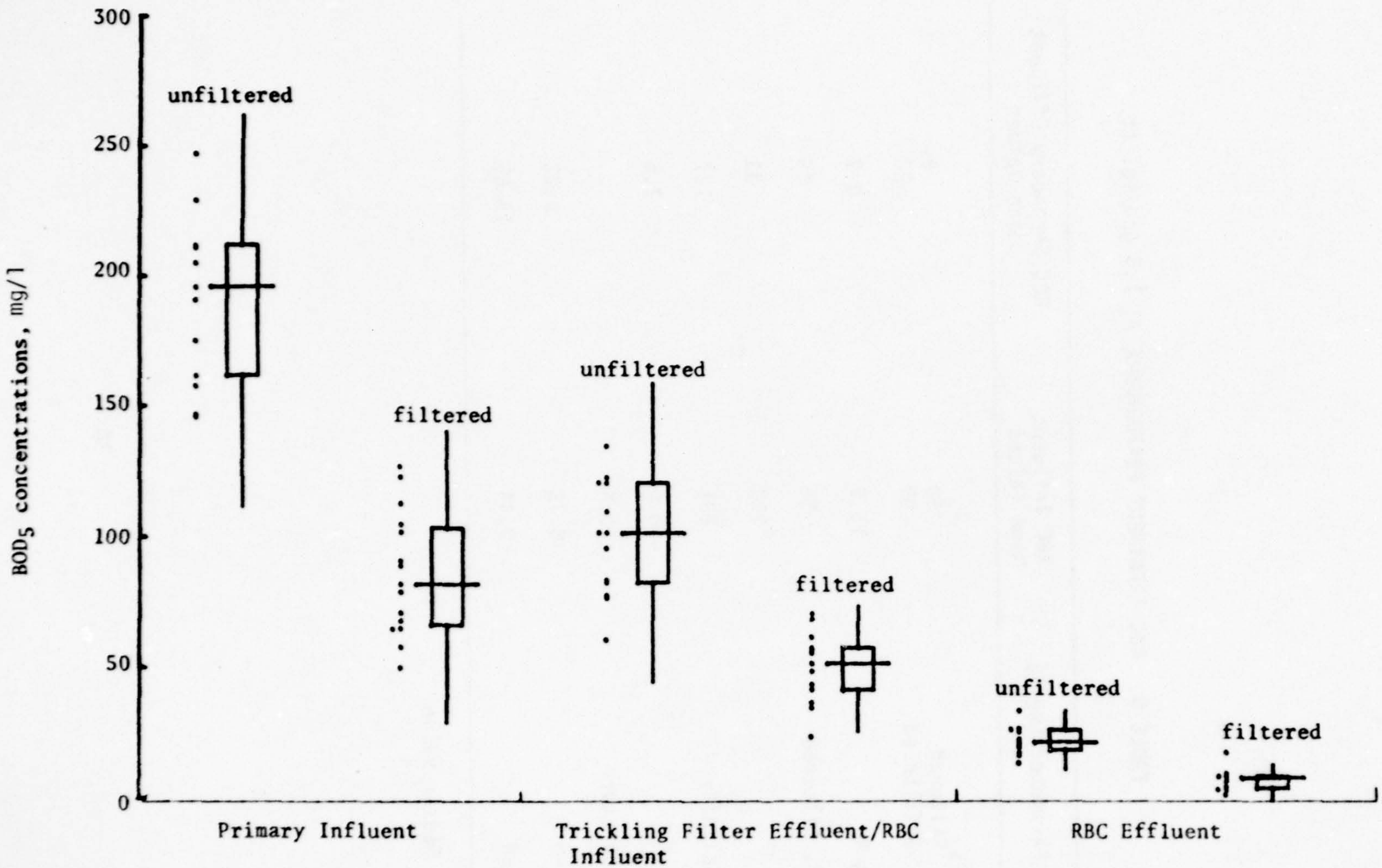

Figure 6. BOD_5 Levels at an RBC Hydraulic Loading of 1.5 gpd/sq. ft.

TABLE 5. RBC TREATMENT PERFORMANCE AT 1.5 gpd/sq. ft.

Parameter (mg/l)	RBC Influent Mean Values	RBC Secondary Effluent Mean Values
BOD_5		
Filtered	50	9
Unfiltered	99	23
NH_3-N	15.9	0.7
TOC, Filtered	35	15
SS	102	33
Alkalinity	231	127
pH[a]	8.6	7.5
Temperature	13.4	-
NO_2-N	0.18	0.22
NO_3-N	0.44	15.65

a. Median value.

unfiltered BOD_5 greater than filtered BOD_5. Because of the effects of suspended solids and nitrification on oxygen demand, unfiltered BOD_5 should not be used alone to evaluate biological treatment efficiency. The difference between values of unfiltered and filtered BOD_5 must be recognized because NPDES permits only require analysis for unfiltered BOD_5 without distinguishing the soluble loading from the particulate loading of a biological treatment process. The difference between unfiltered and filtered BOD_5 values in Figure 6 indicate that pilot studies did not optimize removal of suspended solids. This fact is also shown by the suspended solids data in Table 5. Data for ammonia-nitrogen in Table 5 indicate that nitrification was essentially complete for the RBC secondary effluent and could contribute little to the unfiltered BOD5. Reductions in unfiltered BOD_5 values of Figure 6 should be attempted by removal of suspended solids and not through biological treatment.

Figure 7 shows ammonia removal through biological activity in the trickling filter and RBC processes, where the RBC hydraulic loading was 1.5 gpd/sq. ft. The RBC secondary effluent ammonia level of 0.5 mg/l indicates this to be a highly nitrified wastewater. As discussed in the Literature Review section, removal of nitrogen can be due to both bacteriological assimilation and nitrification. Generally, nitrogen would be assimilated in the amount of about 5 percent of the quantity of carbonaceous oxygen demand utilized, or about 5 percent of the change in filtered BOD_5 across the treatment process. This nitrogen loss/removal should show up in the total Kjeldahl nitrogen (TKN) test (e.g., organic nitrogen plus ammonia) but may not decrease the ammonia level because microorganisms could assimilate nitrogen directly from organic compounds or convert organic nitrogen to ammonia. Removal of nitrogen beyond assimilation should be due to nitrification. The amount of nitrification can be determined from NO_2-N/NO_3-N analyses, since ammonia is oxidized to nitrate. Nitrite and nitrite-nitrate levels are shown in Table 5. The alkalinity test can also be used as a check on the amount of nitrification, because 7.1 mg/l of alkalinity are destroyed per 1 mg/l of NH_3-N oxidized (6). Alkalinity levels are shown in Table 5.

Comparisons of Figures 6 and 7 and Table 5 should be made to evaluate nitrification across the RBC process. Figure 7 shows the RBC influent and RBC secondary effluent levels of ammonia to be 18 and 0.5 mg/l, respectively. This shows that 17.5 mg/l of ammonia-nitrogen were removed across the RBC process, from both assimilation and nitrification. Unfortunately, TKN analyses were not available for this particular study because of equipment problems, and the total nitrogen story cannot be told here. Figure 6 shows that 41 mg/l of filtered BOD_5 were utilized within the RBC process, therefore, 5 percent of 41, or about 2.0 mg/l, of nitrogen would be assimilated by heterotrophic organisms;

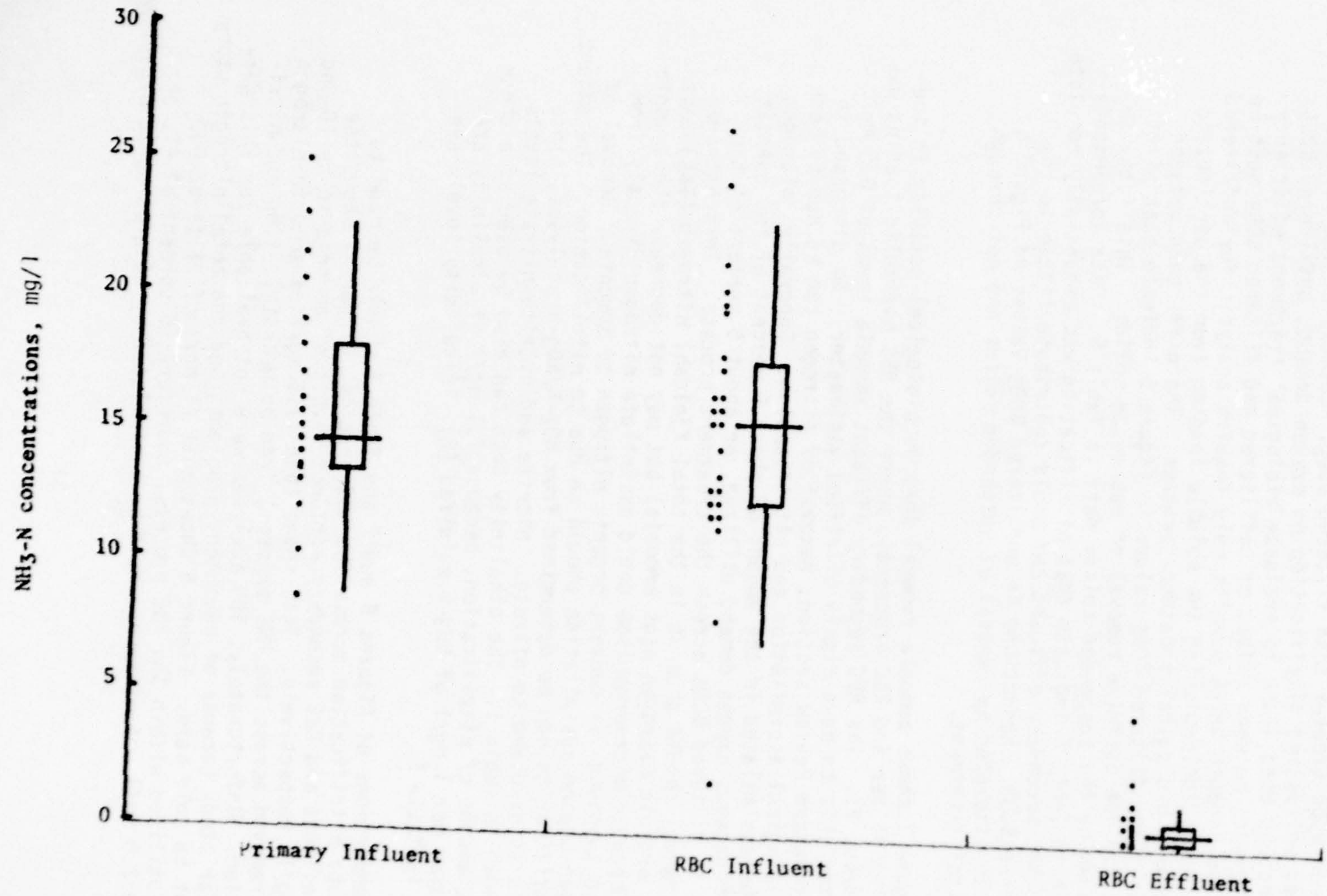

Figure 7. NH_3-N at an RBC Hydraulic Loading of 1.5 gpd/sq. ft.

additional nitrogen would be assimilated by autotrophic organisms. Remaining ammonia would be available for nitrification. Table 5 shows that 14 mg/l of NO_2-N/NO_3-N was formed and represents ammonia oxidized by nitrification. Table 5 also shows 100 mg/l of alkalinity destroyed across the RBC process, and this corresponds to 15 mg/l of ammonia nitrified (e.g., 100 divided by 7.1). In summary, of the nitrogen present in RBC influent, an excess of 2.0 mg/l was assimilated and about 15 mg/l was oxidized. This agrees well with the actual levels of ammonia observed. Ammonia removal was essentially complete in RBC secondary effluent at 1.5 gpd/sq. ft. even though temperature (13.4°C) was poor for nitrification; however, pH had remained near optimum for nitrification. The median pH levels were 7.5 in RBC secondary effluent.

Figure 8 contains results of further studies of secondary treatment by the RBC process following a trickling filter. Supporting data are contained in Tables 6, 7, and 8 for hydraulic loadings of 2.0, 3.0, and 4.0 gpd/sq. ft., respectively. Secondary standards were achieved at all hydraulic loadings as shown by filtered BOD_5 levels for RBC secondary effluent. Filtered BOD_5 values were about 10 mg/l or less for RBC secondary effluent at all hydraulic loadings. Filtered BOD_5 utilized by biological activity within the RBC process (e.g., RBC influent values minus RBC secondary effluent values) were 36, 39 and 38 mg/l at 2.0, 3.0 and 4.0 gpd/sq. ft., respectively. This corresponds to an organic removal rate of about 1.3 lbs. filtered BOD_5/1000 sq. ft.-day at the 4.0 gpd/sq. ft. hydraulic loadings. The organic removal rates should increase if the organic loading were higher. Likewise, filtered TOC utilized within the RBC process were 21, 17, and 17 mg/l at 2.0, 3.0 and 4.0 gpd/sq. ft., respectively. The ratio of filtered BOD_5 utilized to filtered TOC utilized averaged 2.0:1. Wastewater temperature increased slightly at each increased hydraulic loading as shown in Tables 6, 7, and 8. RBC influent pH levels remained at about pH 8.5. It can be concluded from Figure 8 that an existing trickling filter can be upgraded to secondary standards by use of an RBC process at hydraulic loadings up to 4.0 gpd/sq. ft. and at organic removal rates in excess of 1.3 lbs. filtered BOD_5/1000 sq. ft.-day.

Figure 9 shows RBC treatment performance for nitrification at hydraulic loadings of 1.5, 2.0, 3.0 and 4.0 gpd/sq. ft. RBC secondary effluent was highly nitrified at 1.5 gpd/sq. ft. and at 2.0 gpd/sq. ft. for temperatures above 13°C (Table 6). Nitrification was essentially complete at 3.0 and 4.0 gpd/sq. ft. Wastewater temperature was relatively poor for nitrification at 1.5 and 2.0 gpd/sq. ft. (e.g., 13.4 and 15.1°C, respectively) as shown by data in Tables 5 and 6. However, pH levels were near optimum for nitrification at those loadings. RBC secondary effluent pH was about pH 7.5. Wastewater temperature and pH levels were relatively good for nitrification at hydraulic loadings of 3.0 and 4.0 gpd/sq. ft. as shown by data in Tables 7 and 8. Continued good performance by the RBC process at the higher hydraulic loadings is probably attributable to environmental conditions of wastewater temperature and pH.

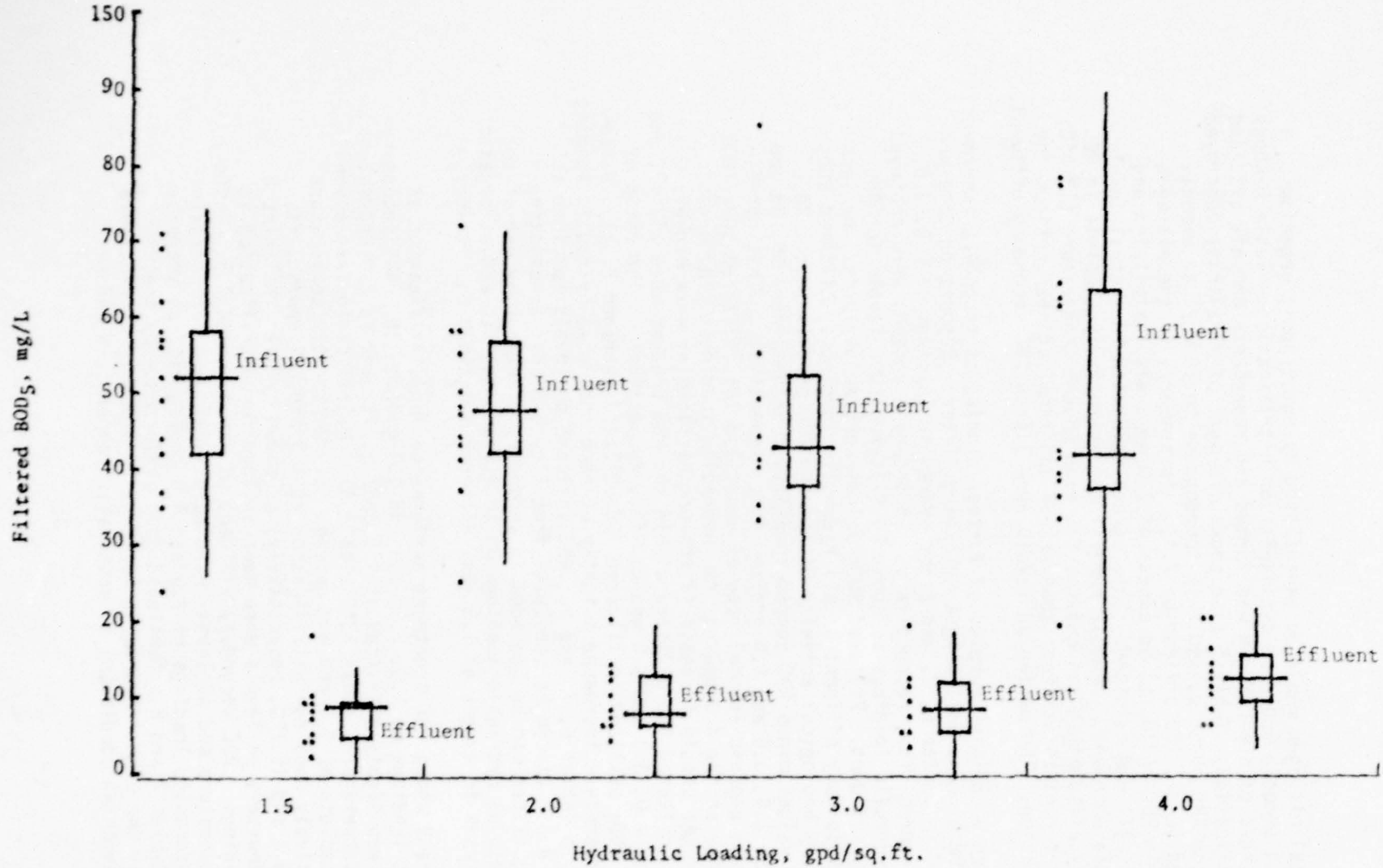

Figure 8. RBC Performance (for BOD_5 Removal) at Various Hydraulic Loading Rates. RBC influent concentrations for BOD are compared to RBC secondary effluent concentrations at each hydraulic loading rate, respectively.

TABLE 6. RBC TREATMENT PERFORMANCE AT 2.0 gpd/sq. ft.

Parameter (mg/l)	RBC Influent Mean Values	RBC Secondary Effluent Mean Values
BOD_5		
Filtered	45	9
Unfiltered	95	32
NH_3-N >13°C	15.2	1.5
NH_3-N <13°C	14.3	5.2
TOC, Filtered	32	11
Suspended Solids	101	25
Alkalinity	212	140
pH[a]	8.3	7.5
Temperature	15.1	-
NO_2-N [b]	0.1	0.5
NO_3-N [b]	0.4	14.9

a. Median value.
b. Limited data.

TABLE 7. RBC TREATMENT PERFORMANCE AT 3.0 gpd/sq. ft.

Parameter (mg/l)	RBC Influent	RBC Secondary Effluent
BOD_5		
Filtered	64	9
Unfiltered	100	-
NH_3-N	12.2	2.7
TOC, Filtered	35	18
Suspended Solids	112	72
Alkalinity	215	157
pH[a]	8.5	7.4
Temperature	16.8	-
NO_2-N[b]	0.18	0.39
NO_3-N[b]	0.16	11.30

a. Median value.
b. Limited data.

TABLE 8. RBC TREATMENT PERFORMANCE AT 4.0 gpd/sq. ft.

Parameter (mg/l)	RBC Influent Mean Values	RBC Secondary Effluent Mean Values
BOD_5		
Filtered	49	11
Unfiltered	81	-
NH_3-N	12.5	2.8
TOC, Filtered	32	15
Suspended Solids	55	26
Alkalinity	209	146
pH[a]	8.0	7.3
Temperature	20.6	-

a. Median value.

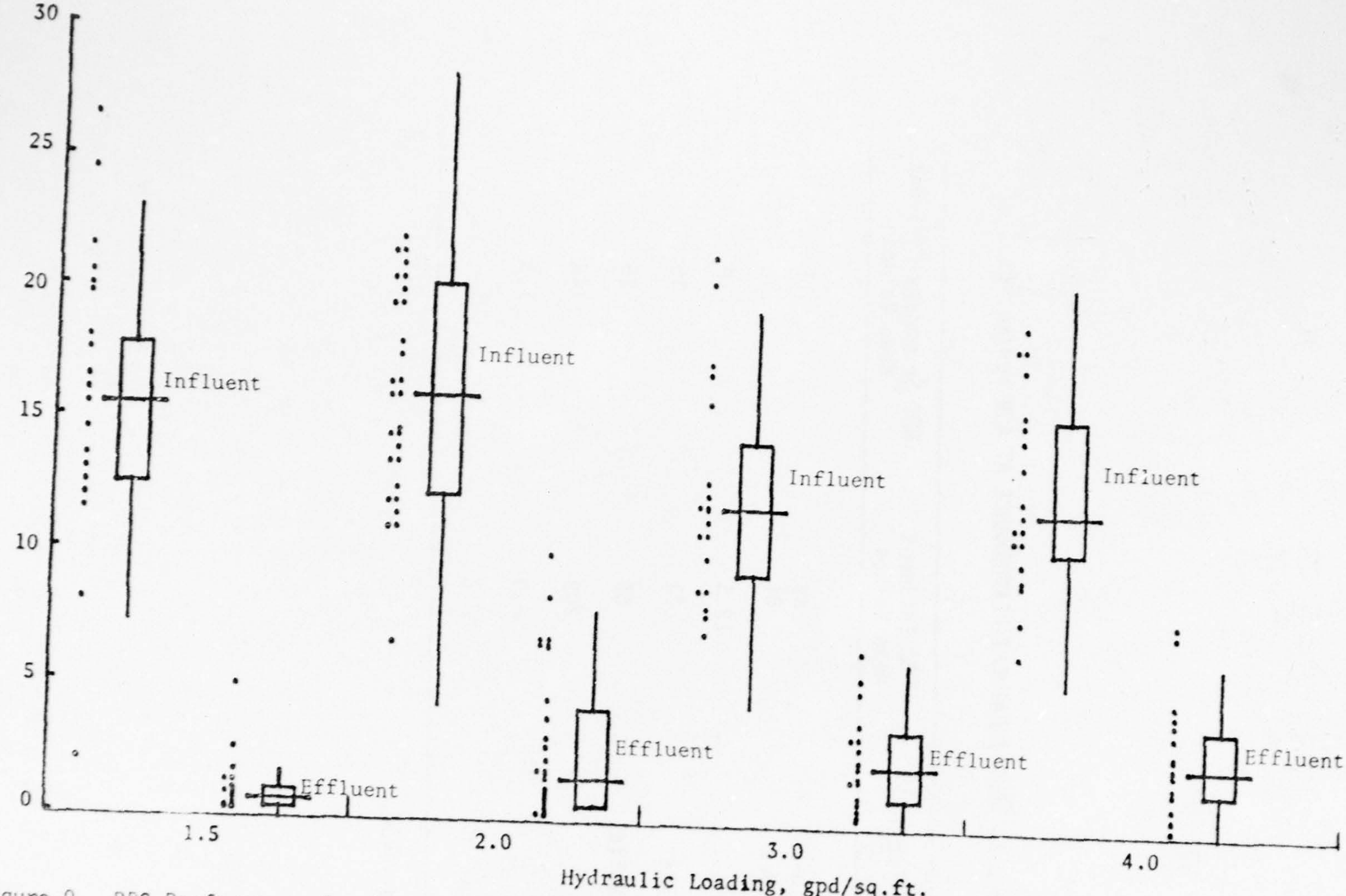

Figure 9. RBC Performance for Ammonia-Nitrogen at Various Hydraulic Loading Rates. RBC influent concentrations of ammonia-nitrogen are compared to RBC secondary effluent concentrations at each hydraulic loading rate, respectively.

Combined use of Figures 8 and 9 and applicable Tables with supporting data are necessary to fully evaluate nitrification across the RBC process. Figure 8 showed that about 40 mg/l of filtered BOD_5 was utilized across the RBC process at each hydraulic loading; this represents about 5 percent of 40 or 2.0 mg/l of nitrogen assimilated by heterotrophic organisms. Additional nitrogen would be assimilated by autotrophic nitrifying organisms. Data in Tables 5, 6, 7, and 8 show nitrate levels present in RBC secondary effluent, and show the alkalinity destroyed by the RBC process to compare favorably with ammonia levels. For example, at the hydraulic loading of 4.0 gpd/sq. ft., 63 mg/l of alkalinity were destroyed, corresponding to 8.9 mg/l of ammonia-nitrogen removal by nitrification. To balance nitrogen losses at 4.0 gpd/sq. ft., 8.9 mg/l would be added to 2.0 or more mg/l, showing total nitrogen assimilated and nitrified to be about 11.0 mg/l. This compares well with observed ammonia levels of 12 mg/l in RBC influent and 2.0 mg/l in RBC secondary effluent, or 10 mg/l ammonia-nitrogen removed at 4.0 gpd/sq. ft. Organic nitrogen was unaccounted for and would represent a fraction of the nitrogen assimilated or present as ammonia in the RBC secondary effluent.

The effect of wastewater temperature on secondary treatment and nitrification across the RBC process can be seen by use of Figure 10. This Figure shows the temperature profile and RBC secondary effluent ammonia levels during the period December 15, 1976 to January 11, 1977, at a hydraulic loading of 2.0 gpd/sq. ft. The RBC secondary effluent was highly nitrified during the period of December 15-28 as evidenced by an average ammonia-nitrogen level of 1.0 mg/l. Ammonia nitrogen levels in the RBC secondary effluent increased to about 6.0 mg/l during the period of January 3-11, after wastewater temperatures had dropped to about 10°C. Decreased ammonia removal lagged behind this temperature drop, but the effect was substantial in lessening the degree of nitrification. Both organic removal and nitrification rates should have been affected by the drop in wastewater temperature. Decreased nitrification rates should be about half for each 10°C drop (6), while organic removal rates (secondary treatment) should be about 75 percent for each 10°C drop (2). Combined temperature effects from decreased organic removal and nitrification rates resulted in the increased ammonia levels shown in Figure 10. Treatment progression within the RBC process should show those effects, since organic removal occurs in the initial stages and nitrification in the later stages. Progression of treatment is shown in Figure 11 and indicates higher rates of nitrification at higher temperatures.

Figure 12 shows the progression of nitrification within the RBC process at the 1.5 gpd/sq. ft. hydraulic loading. Grab samples were used for data presented in Table 9 and shown in Figure 12 and should represent a valid picture of RBC stage-by-stage performance,

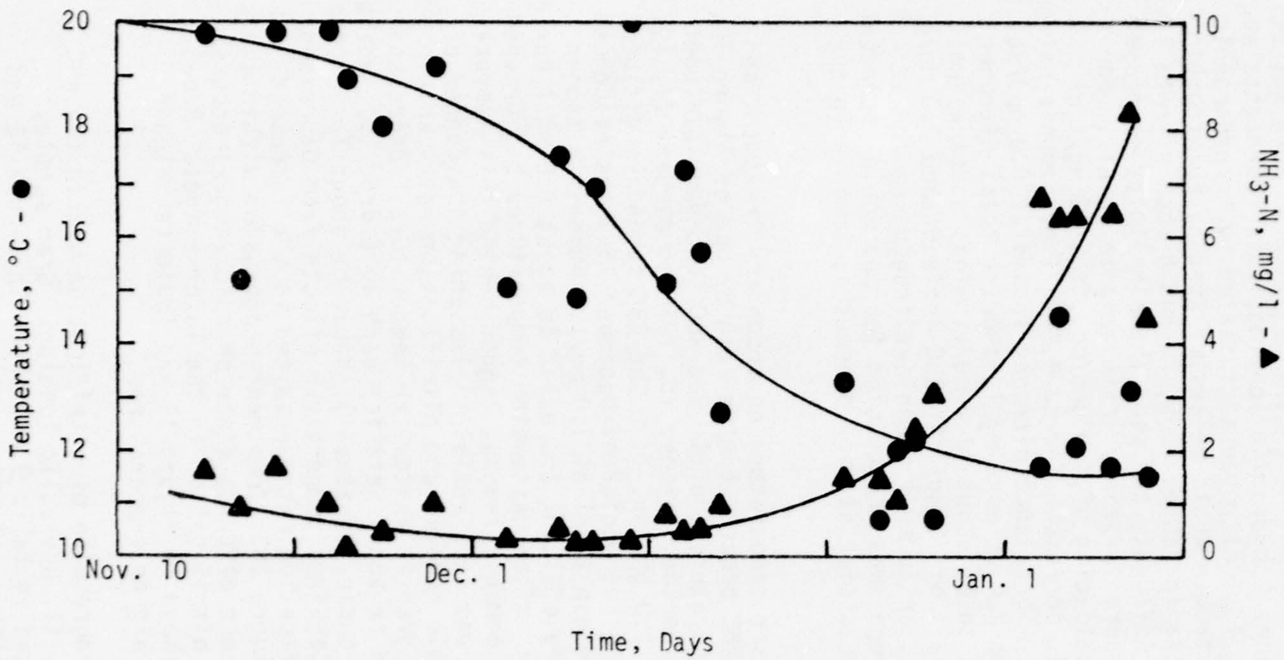

Figure 10. Effect of Temperature on RBC Effluent NH_3-N Concentrations at a Hydraulic Loading of 2.0 gpd/sq. ft.

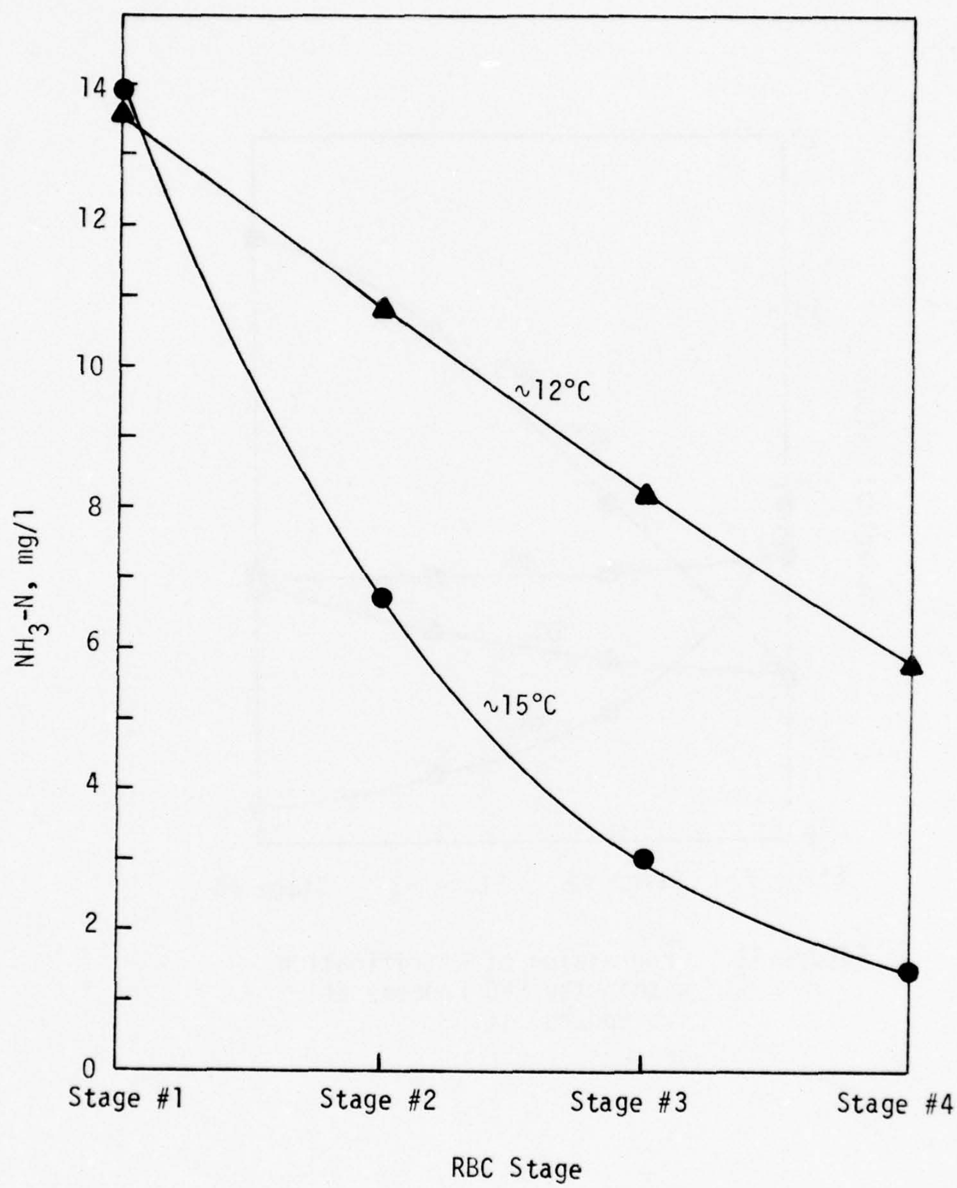

Figure 11. Progression of Treatment within the RBC Process at 2.0 gpd/sq. ft., Showing Temperature Effect.

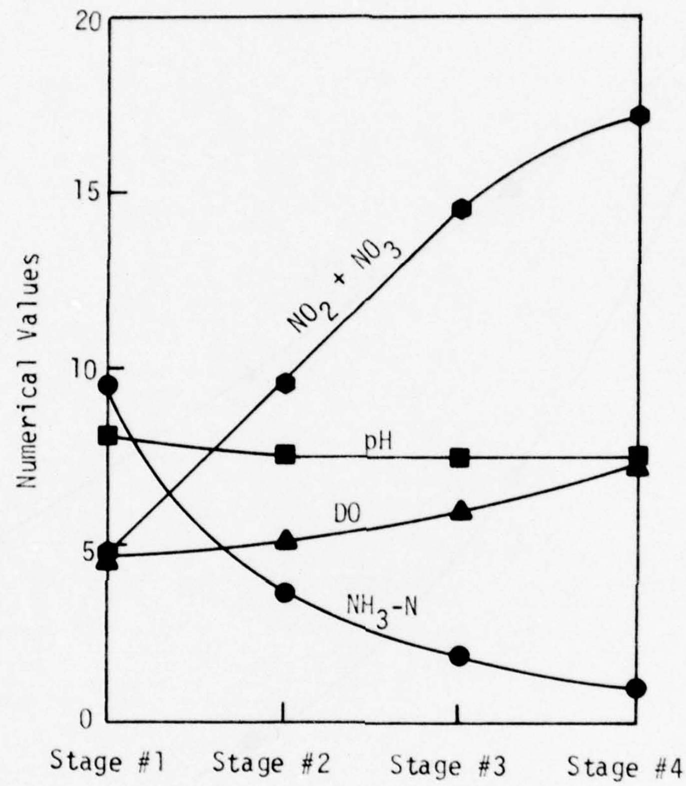

Figure 12. Progression of Nitrification within the RBC Process at 1.5 gpd/sq. ft.

TABLE 9. NITRIFICATION WITHIN THE RBC TREATMENT PROCESS AT VARIED HYDRAULIC LOADING RATES

RBC Stage Number	Parameter				
	NH_3-N	pH	DO	°C	$NO_2 + NO_3 - N$
I. 1.5 gpd/sq. ft.					
1	9.4	8.0	4.6	13.2	4.68
2	3.6	7.5	5.1	12.7	9.60
3	1.8	7.4	5.9	12.4	14.56
4	0.9	7.5	7.2	12.2	17.24
II. 2.0 gpd/sq. ft.					
1	13.4	7.9	3.5	12.7	-
2	8.4	7.7	4.1	12.2	-
3	3.7	7.6	4.6	11.9	-
4	1.8	7.5	5.0	11.7	-
III. 3.0 gpd/sq. ft.					
1	11.1	8.2	5.1	17.5	4.70
2	9.7	7.7	4.9	17.3	5.73
3	6.2	7.5	5.1	17.2	9.15
4	3.6	7.4	5.3	17.3	13.60
IV. 4.0 gpd/sq. ft.					
1	12.7	7.9	4.5	20.2	-
2	9.6	7.4	4.2	19.8	-
3	5.3	7.2	4.2	19.7	-
4	2.3	7.2	4.8	19.7	-

because flow equalization had occurred within treatment processes before RBC treatment. Nitrification was occurring in Stage 1 and subsequent stages as evidenced by formation of nitrate and removal of ammonia. It is also evident that nitrification and organic removal were occurring simultaneously within the intial stages because the filtered BOD_5 and TOC levels dropped across the RBC process (Table 5), even though organic removal data was not taken within RBC stages. Ammonia was removed in greater quantity than nitrate formed; the difference, about 3.0 mg/l, is attributed to assimilation by both heterotrophs and autotrophs. Dissolved oxygen levels remained ideal for nitrification in all RBC stages. The pH drop from stage to stage was caused by biological recarbonation plus destruction of alkalinity by nitrification.

Ammonia-nitrogen removal patterns through the trickling filter and RBC processes are shown in Table 10. These data are typical of near secondary treatment by the trickling filter and additional secondary treatment and nitrification by the RBC process. Changes in ammonia level show that little nitrification occurred in the first RBC stage, while higher rates of nitrification occurred in Stages 2 and 3, and a lower rate of nitrification occurred in Stage 4 for this particular study. Similiarly, Figure 13 shows progression of nitrification within the RBC process at various hydraulic loadings of 1.5, 2.0, 3.0 and 4.0 gpd/sq. ft. Rates of nitrification appeared to reach a maximum level at each loading, and then decreased in the last RBC stage. This points out several issues of ammonia-nitrogen removal. First, nitrification rate is influenced by organics removal, and organic removal seems to take precedence. Ammonia removal in Stage 1 shows this influence by organic removal. Ammonia removal in Stages 2 and 3 indicate that nitrification rates are relatively unaffected by ammonia concentrations above about 5 mg/l, while Stage 4 results indicate that nitrification rate has decreased due to limited concentrations of ammonia. That is, nitrification rates approximate a zero-order reaction above about 2.5 mg/l and first-order reaction below 2.5 mg/l (6). This explains why stringent NPDES permit limitations of $\leq$ 2.0 mg/l makes compliance difficult.

No Intermediate Settling

Further studies of the RBC process for secondary treatment and nitrification following a trickling filter were made at hydraulic loading of about 3.0 gpd/sq. ft. without intermediate settling between the trickling filter and RBC process. These studies were conducted to evaluate the possibility of upgrading existing trickling filter plants by use of RBC processes while maintaining existing secondary clarifiers to settle out RBC effluent. This scheme should result in savings on total wastewater treatment plant upgrade by making maximum use of existing facilities. These

studies were conducted with RBC influent pH elevated to about pH 8.0 to create good environmental conditions for nitrification, and separately with neutral pH for the RBC influent to evaluate pH effect on nitrification.

TABLE 10. AMMONIA-NITROGEN REMOVAL PATTERNS THROUGH THE TREATMENT PROCESS AT 1.8 gpd/sq. ft. THROUGH THE RBC

	NH_3-N Removed		
Sample Point	(mg/l)	% Removed By Process	Cummulative Removed (%)
1° Influent	20.3	0	0
1° Effluent	18.7	7.9	7.9
TF 2° Effluent	13.1	27.6	35.5
RBC Stage #1	12.1	4.9	40.4
RBC Stage #2	6.7	26.6	67.0
RBC Stage #3	2.9	18.7	85.7
RBC Stage #4	1.4	7.4	93.1
RBC 2° Effluent	1.8	-	91.1

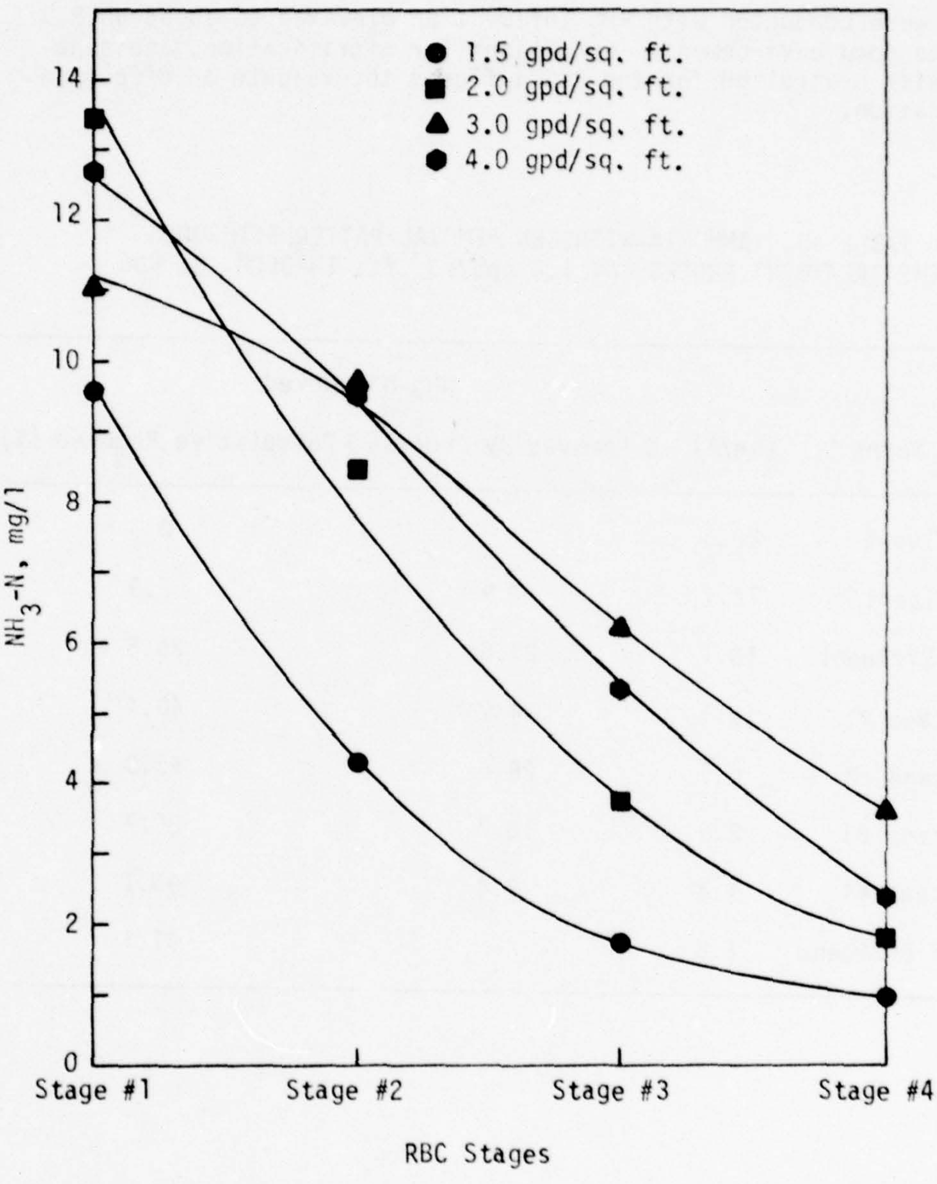

Figure 13. Progression of Nitrification within the RBC Process at Various Hydraulic Loadings.

Figure 14 shows secondary treatment performance of the trickling filter and RBC treatment processes at 3.0 gpd/sq. ft. without intermediate settling between the trickling filter and RBC process. Filtered BOD_5 values show that the RBC secondary effluent met secondary standards. It can be concluded from Figure 14 that the RBC process can be used to upgrade an existing trickling filter to secondary standards without intermediate settling between the trickling filter and RBC process.

Ammonia removal across the trickling filter and RBC process is shown in Figure 15, where the RBC process treated wastewater effluent at a hydraulic loading rate of 3.0 gpd/sq. ft. without intermediate settling after the trickling filter. The ammonia level of 2.0 mg/l in the RBC secondary effluent shows this to be a well nitrified effluent. Supporting data in Table 11 for alkalinity indicate that about 15.9 mg/l of ammonia was removed by nitrification (e.g., 113 divided by 7.1). Temperature and pH were both near optimum for this study as shown by data in Table 11. Performance of the RBC process following a trickling filter without intermediate settling compares favorably with performance where intermediate settling was used at similar hydraulic loadings (See Figure 9). It can be concluded from use of Figures 9 and 15 that nitrification across an RBC process is not greatly influenced by intermediate settling between the trickling filter and RBC process.

Progression of treatment within the RBC stages at 3.0 gpd/sq. ft. following a trickling filter without intermediate settling is shown in Figure 16. This shows that rates of nitrification were relatively low in Stage 1 and higher in Stages 2 and 3, and again lower in Stage 4. This is similar to results of Figure 13 where intermediate settling had been used before the RBC process. Again, these rates of nitrification show that organic removal affects nitrification rates in the initial RBC stages where secondary treatment takes place and nitrification rates are highest at ammonia levels above about 5 mg/l--where the rate of reaction is reported to be zero-order (6). Nitrification rates decrease when the ammonia level drops below about 5 mg/l so that the latter stage of treatment is less efficient, and stringent NPDES permits become more difficult and costly to meet.

The effect of pH on nitrification across the RBC process is shown in Figure 17, where the RBC process followed the trickling filter without intermediate settling. RBC secondary effluent ammonia levels increased from about 1.5 mg/l with elevated pH adjustment before the RBC process to about 10 mg/l at neutral pH levels. Good nitrification within the RBC process continued for about 4 days after elevated pH changed to neutral levels. Then, poor nitrification continued for the duration of the study at neutral pH. Figure 17 shows the benefit of chemical feed for pH and alkalinity control for nitrification. Reportedly, elevated pH primarily increases the ratio of nitrifiers to heterotrophs in the system (6).

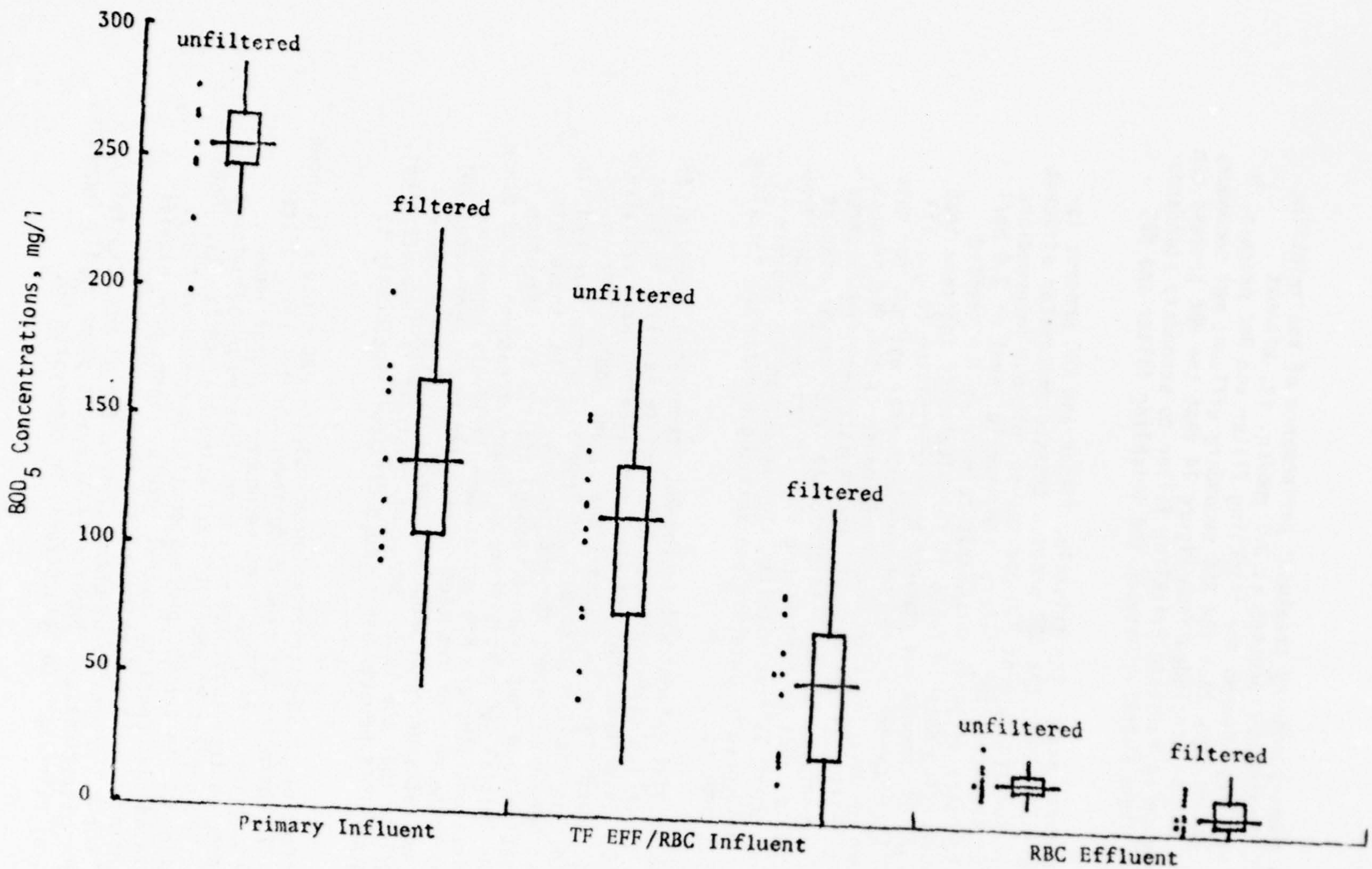

Figure 14. BOD Removal Throughout Wastewater Treatment Processes without Intermediate Settling. The RBC received a wastewater with elevated pH at a hydraulic loading rate of 3.0 gpd/sq. ft.

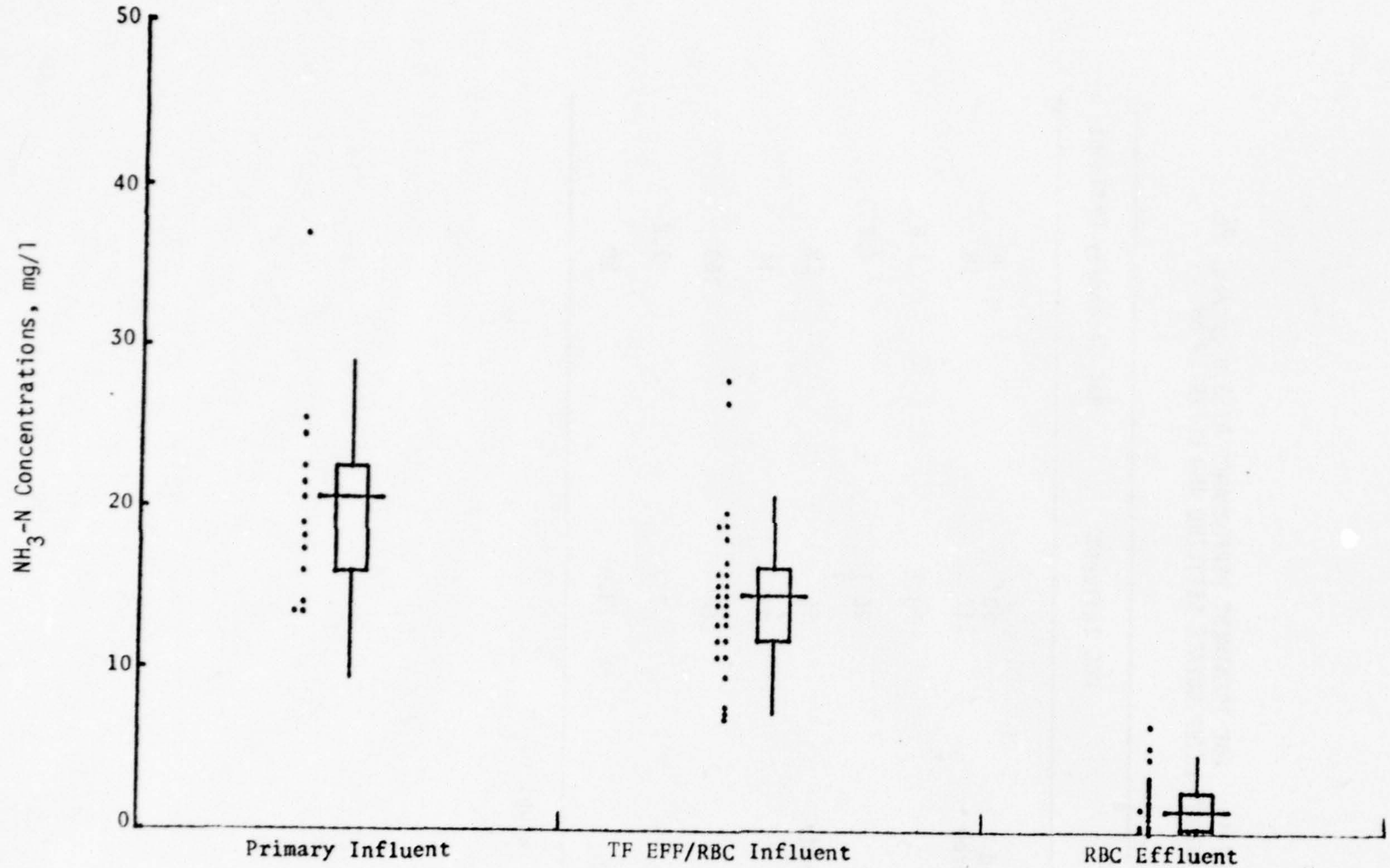

Figure 15. Ammonia-Nitrogen Removal Throughout Wastewater Treatment Processes without Intermediate Settling. The RBC received a wastewater with elevated pH at a hydraulic loading of 3.0 gpd/sq. ft.

TABLE 11. RBC TREATMENT PERFORMANCE AT 3.0 gpd/sq. ft. WITHOUT INTERMEDIATE SETTLING AND ELEVATED pH

Parameter	RBC Influent	RBC Secondary Effluent
BOD_5		
Filtered	53	8
Unfiltered	122	18
NH_3-N	18.2	1.6
TKN	26.1	4.2
COD, Filtered	56	20
SS	77	12
Alkalinity	266	153
pH[a]	7.7	7.2
Temperature	23.9	ND

a. Median value.

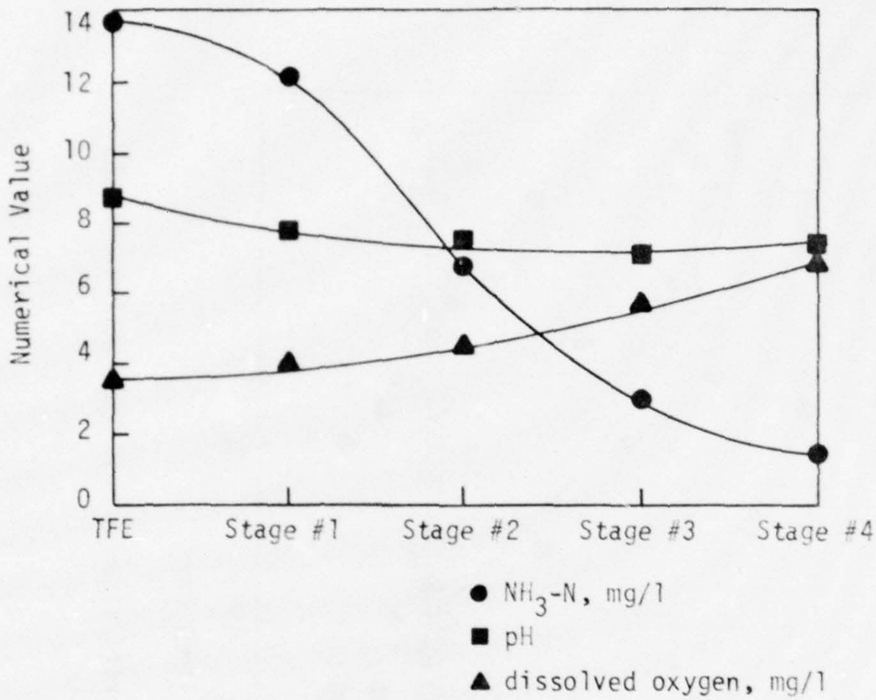

Figure 16. Progression of Nitrification within the RBC Process at 3.0 gpd/sq. ft. Following a Trickling Filter without Intermediate Settling.

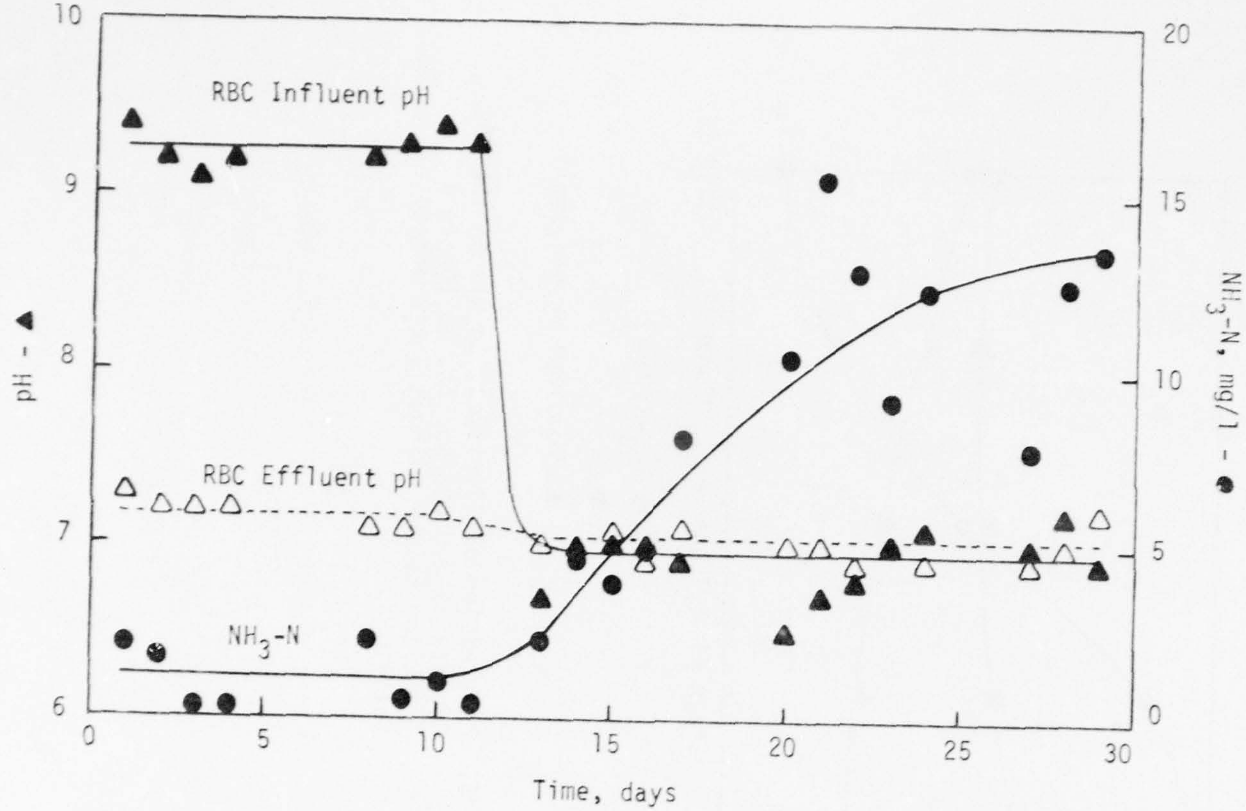

Figure 17. Effect of pH on Nitrification Across the RBC Process at 3.0 gpd/sq. ft.

This favors simultaneous nitrification and organic removal in initial RBC stages and higher nitrification rates in latter stages for elevated pH levels, but not for neutral pH.

Further study of the pH effect on nitrification was conducted by repeating the neutral pH conditions for RBC performance without intermediate settling after the trickling filter. Results of both studies at neutral pH without intermediate settling are presented in Table 12. Figure 18 shows ammonia levels for RBC influent and RBC secondary effluent. RBC performance for nitrification was relatively good with elevated pH as indicated by an effluent ammonia level of 1.6 mg/l, but poor with neutral pH as indicated by effluent ammonia levels of 12.7 mg/l and 8.8 mg/l for the two studies. Supporting data in Table 12 for alkalinity and TKN confirm the poor nitrification at neutral pH levels; 66 mg/l of alkalinity were destroyed indicating 9.3 mg/l of ammonia nitrified at neutral pH values. The RBC secondary TKN effluent value was 9.0 mg/l, again indicating poor nitrification at neutral pH.

Data in Table 12 for filtered BOD_5 and TOC indicate that secondary effluent standards were achieved by the RBC process at neutral pH. RBC secondary effluent filtered BOD_5 values were 8 and 10 mg/l for the two studies, and 21 and 22 mg/l of TOC were removed by the RBC process. This secondary treatment performance by the RBC process at both neutral pH levels compares favorably with RBC performance at elevated pH levels of about pH 8.0 shown in Figure 14 and Table 11. It can be concluded that elevated pH levels of about pH 8.0 do not affect secondary treatment performance (BOD_5 removal) of the RBC process.

Organic Loading

Further studies of the RBC process for secondary treatment and nitrification were made at hydraulic loadings of about 3.0 gpd/sq. ft. to evaluate the effect of organic loading on secondary treatment and nitrification. These studies evaluated the effect of partial and complete secondary treatment by an existing trickling filter, versus no secondary treatment, prior to an RBC process for secondary treatment and/or nitrification. These studies should help answer the question arising in design upgrades, "Should existing facilities be abandoned, or used?". The result should be that increasing organic loading increases effluent ammonia levels unless additional RBC surface area is available at higher organic loadings, because substantial organic removal must occur before nitrification begins (38). Therefore, the use of existing facilities for organic removal should substantially reduce surface area requirements of the RBC process for further secondary treatment plus nitrification. For example, Antonie showed that a 6 MGD, mechanical drive RBC plant for

TABLE 12. RBC TREATMENT PERFORMANCE AT NEUTRAL pH AND 3.0 gpd/sq. ft. WITHOUT INTERMEDIATE SETTLING

Parameter	(Summer 1977) RBC Influent	RBC Effluent	(Spring 1978) RBC Influent	Stage #2	RBC Effluent
BOD_5 (mg/l)					
Filtered	39	8	57	18	10
Unfiltered	146	68	ND	ND	ND
TOC (mg/l)	43	22	46	34	24
NH_3-N (mg/l)	19.5	8.8	24.6	ND	12.7
TKN (mg/l)	27.1	10.4	24.3	ND	9.0
COD, Filtered (mg/l)	99	38	166	ND	61
Alkalinity (mg/l)	204	140	167	ND	101
pH [a]	7.0	7.1	6.7	6.8	6.9
Temperature	24.9	ND	17.4	ND	ND

a. Median value.

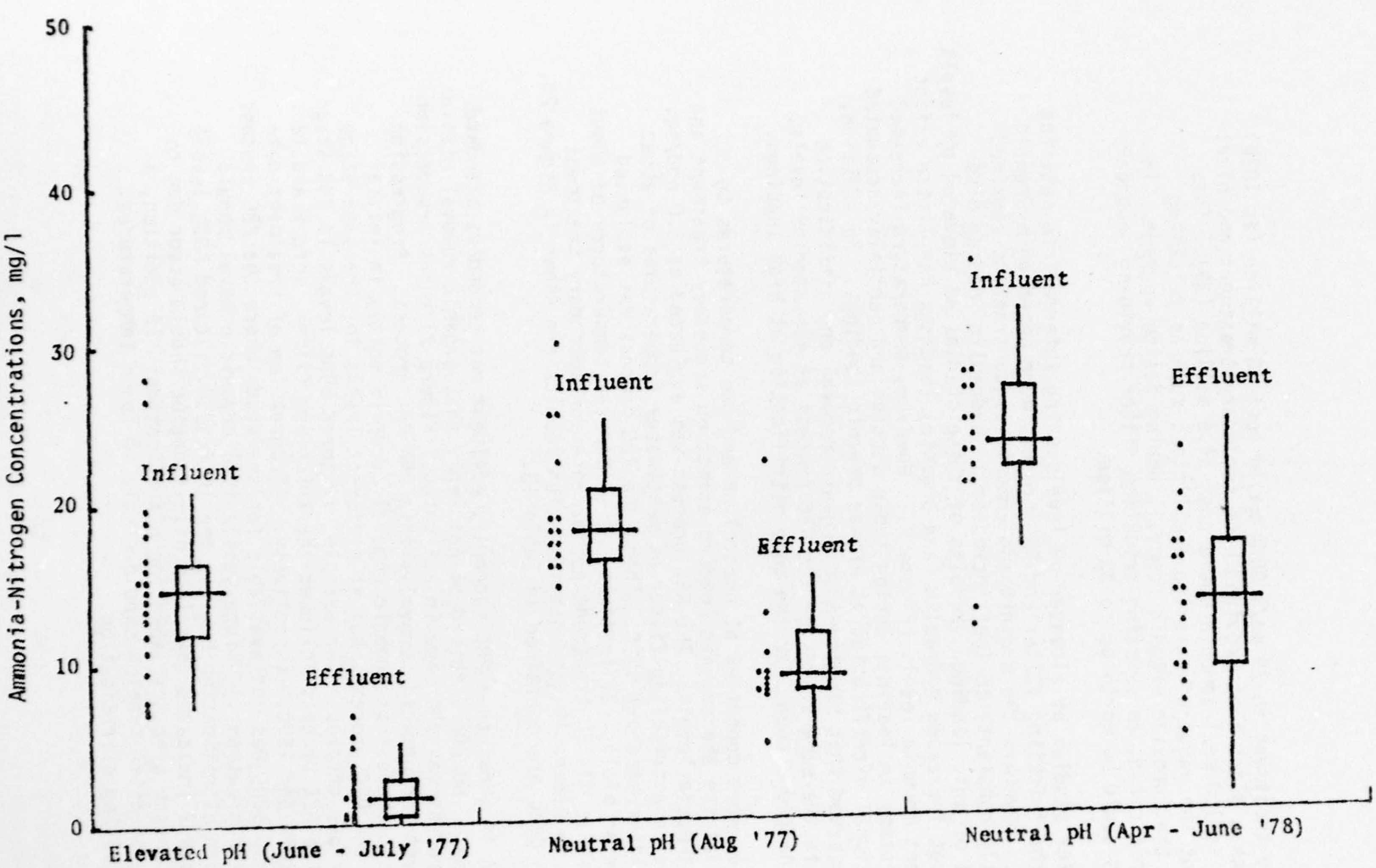

Figure 18. RBC Performance for Nitrification at 3.0 gpd/sq. ft. without Intermediate Settling. RBC influent and RBC secondary effluent ammonia-nitrogen concentrations are shown for elevated and neutral pH values.

secondary treatment to 20 mg/l BOD_5 would cost $3 million (in 1976) while such a plant that provided both secondary treatment and nitrification to 1.0 mg/l ammonia would cost $4.5 million (39). This points out the value of existing facilities, such as trickling filters, that provide organic removal, during design upgrade. In the example cited, an existing trickling filter providing secondary treatment could be worth up to $3 million.

Earlier studies at elevated pH levels using intermediate settling between the trickling filter and RBC process were based on hydraulic loadings. However, the organic and ammonia concentrations remained essentially constant, so that increases in hydraulic loading also increased organic loading. Results of these studies at elevated pH levels showed that increased hydraulic (and organic) loadings had little effect on effluent ammonia levels (Figure 9). However, temperature increased with increases in loadings during those studies and partially accounted for additional nitrification at higher organic loadings. In addition, it was observed that simultaneous organic removal and nitrification occurred in the same stages of the RBC process at elevated pH levels, and this helped account for the good nitrification at high loadings.

Studies were conducted at neutral pH and two temperatures to further evaluate the organic loading effect on secondary treatment and effluent ammonia levels. The RBC process was evaluated at 3.0 gpd/sq. ft. following a trickling filter at wastewater temperatures of about 20°C and later at about 15°C. Then, the RBC process was evaluated without prior biological treatment at wastewater temperatures of about 20°C. Results of RBC treatment performance for secondary treatment are shown in Figure 19, and nitrification results are shown in Figure 20. Supporting data are contained in Table 13.

Figure 19 shows that RBC secondary effluent met secondary standards in all cases. However, this does not imply that organic removal within the RBC process was the same in all cases. Figure 21 shows progression of treatment for organic removal within the RBC process. Progression of treatment shows that organic removal occurred mostly in initial stages of the RBC process, but at different levels for the same stage during various studies. For example, filtered BOD_5 levels in RBC Stage 2, where the RBC process followed the trickling filter, were 8 and 18 mg/l for 20°C and 15°C, respectively. (Progression of treatment data for filtered BOD_5 was not available for the study where the RBC process had no prior treatment.) Since substantial organic removal should occur before nitrification begins, the increased filtered BOD_5 level in RBC Stage 2 indicates that less nitrification should occur due to less RBC surface area available for nitrification. In addition, a lower rate of nitrification should result at lower temperatures, further limiting nitrification.

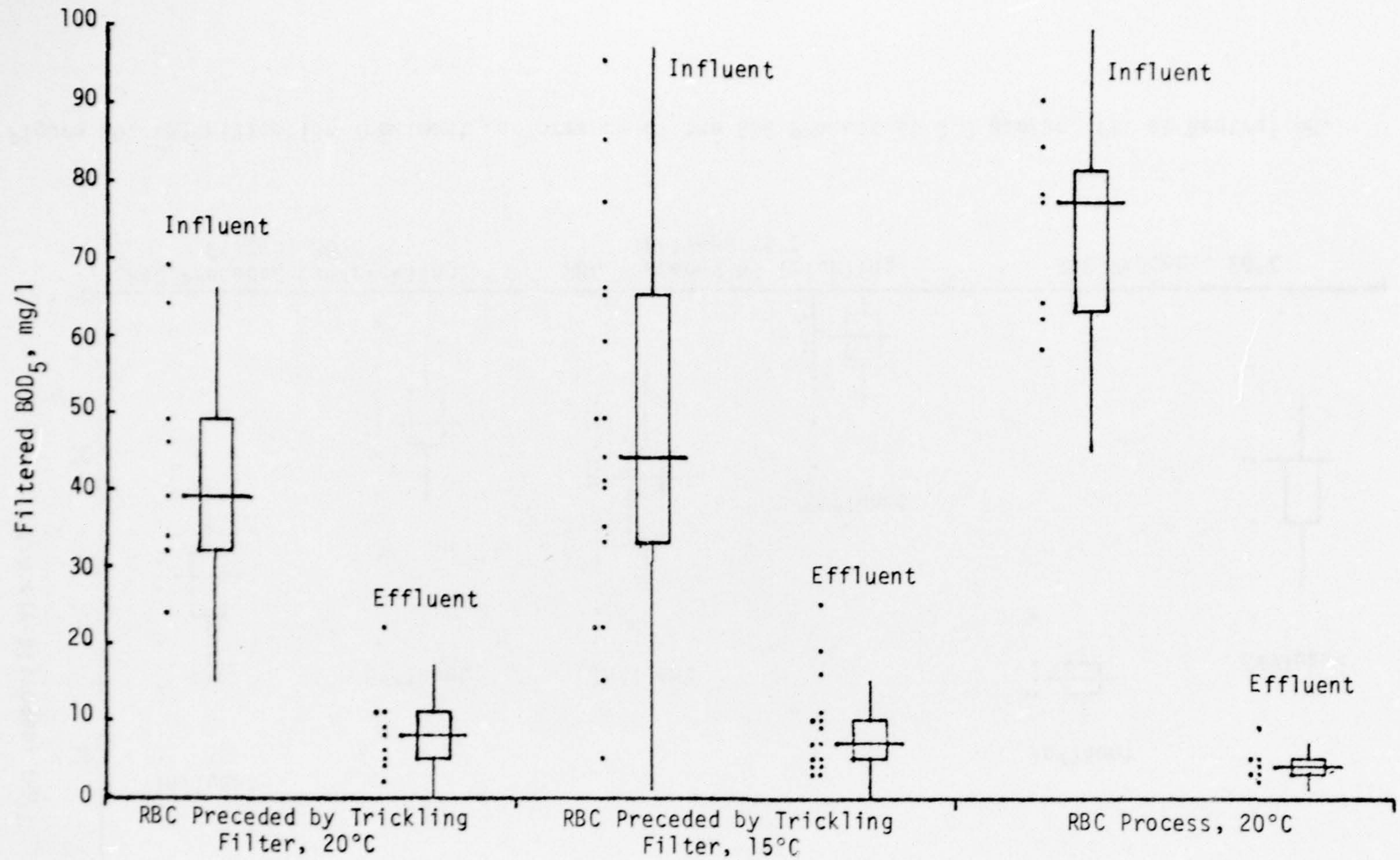

Figure 19. Secondary Treatment Performance of the RBC Process at 3.0 gpd/sq. ft. at Neutral pH.

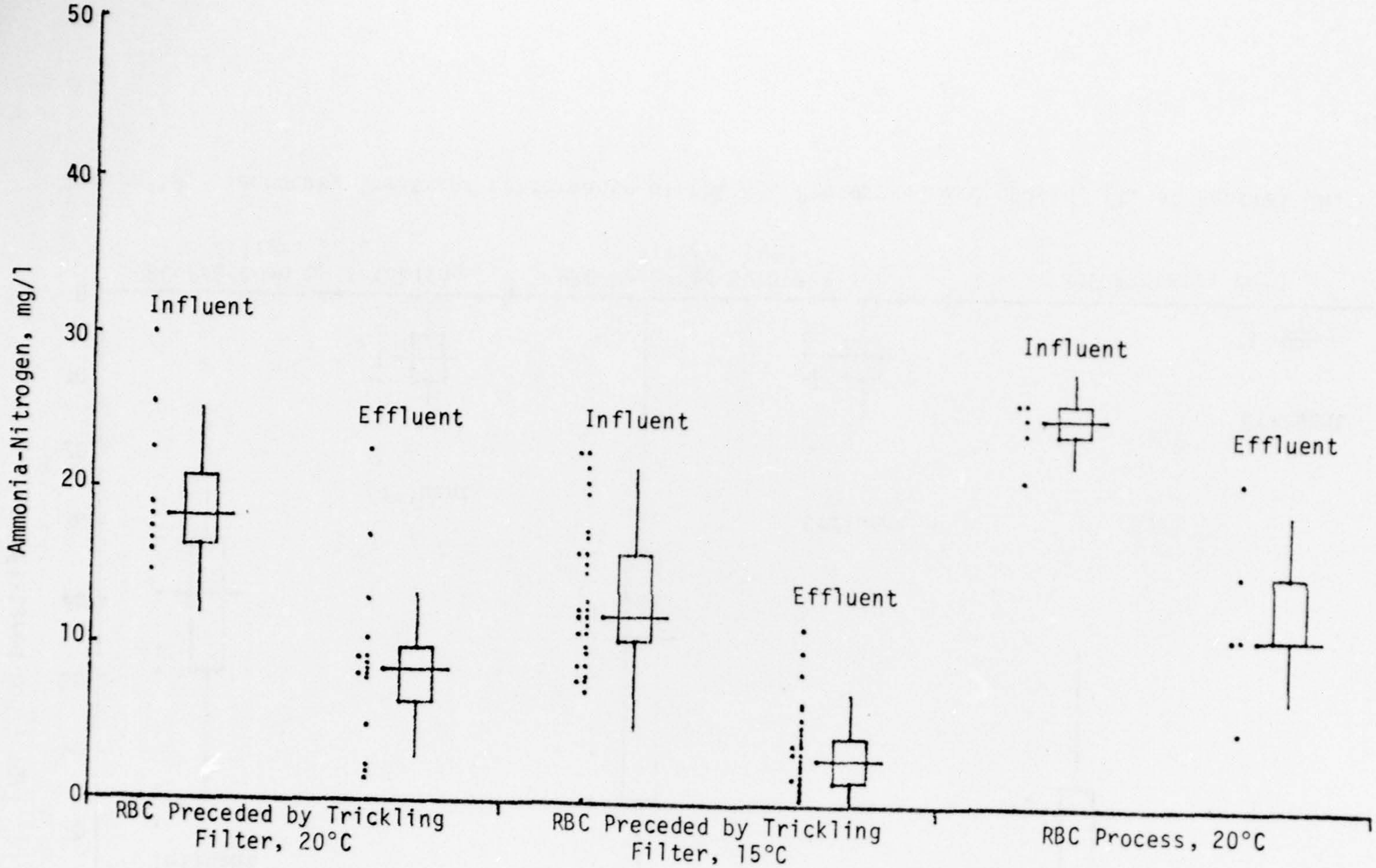

Figure 20. Nitrification Treatment Performance of the RBC Process at 3.0 gpd/sq. ft. at Neutral pH.

TABLE 13. RBC TREATMENT PERFORMANCE AT 3.0 gpd/sq. ft. AND VARIED ORGANIC LOADS

Parameter	Trickling Filter plus RBC Process, 20°C RBC Influent	/ Effluent	Trickling Filter plus RBC Process, 15°C RBC Influent	/ Effluent	RBC Process, 20°C RBC Influent	/ Effluent
BOD_5 (mg/l)						
Filtered	43	9	47	9	73	5
Unfiltered	136	22	90	ND	161	11
NH_3-N (mg/l)	19.5	8.8	12.9	3.4	24.4	12.6
TKN (mg/l)	27.1	11.6	ND	ND	28.8	13.5
COD, Filtered (mg/l)	98	38	83	36	197	134
Alkalinity	203	140	228	159	223	193
pH[a]	7.1	7.1	8.5	7.4	8.8	7.2
Temperature	24.2	25.5	17.5	17.0	24.4	ND

a. Median value.

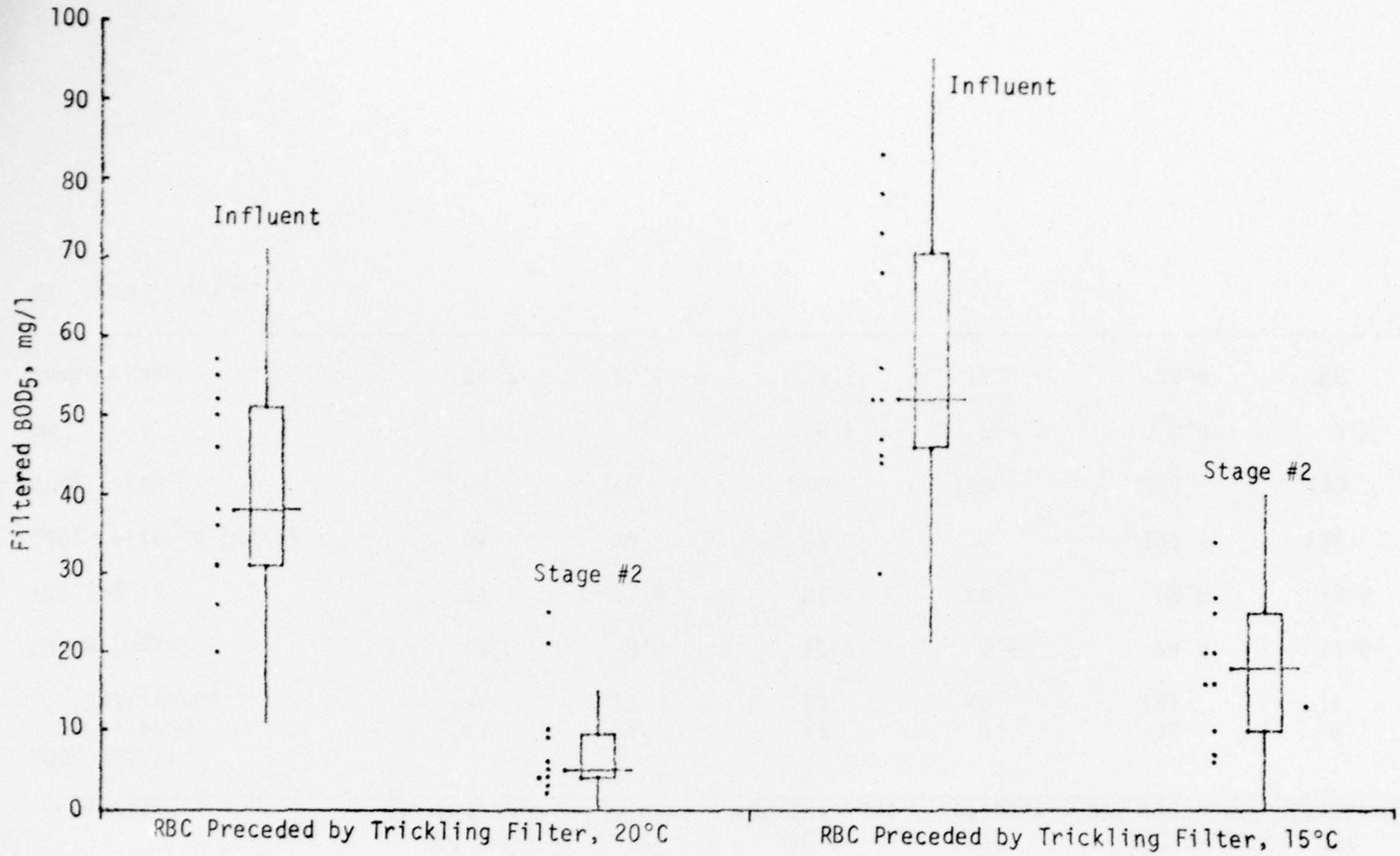

Figure 21. Progression of Secondary Treatment within the RBC Process at 3.0 gpd/sq. ft.

Figure 20 shows that nitrification was near completion at 20°C with lower organic loading on the RBC process; whereas, nitrification was relatively poor at the lower temperatures with higher organic loading to the RBC process. These results indicate higher organic loadings, which in turn increase effluent ammonia levels, because substantial organic removal must occur before nitrification begins. Lower temperatures seemed to have a similar effect on effluent ammonia levels, like that observed with increased organic loading.

SUMMARY AND CONCLUSIONS

The RBC process performed effectively as a system to upgrade an existing trickling filter plant when used for secondary treatment over a range of hydraulic loads from 1.5 to 4.3 gpd/sq. ft. Secondary treatment was less noticeably affected by wastewater temperature than was nitrification. Results also indicated that elevating the RBC influent pH to about pH 8.0 increased the nitrification rate. The increase in nitrification rates decreases the RBC surface area requirements resulting in less costly wastewater treatment plant upgrades.

An existing trickling filter plant can be upgraded to secondary standards for BOD_5 by using a rotating biological contactor (RBC) process for organic removal without intermediate settling between the trickling filter and RBC process.

An existing trickling filter plant can be upgraded for ammonia removal by using an RBC process for nitrification without intermediate settling between the trickling filter and RBC process.

The use of existing trickling filter plants for partial or complete secondary treatment decreases the surface area requirements of RBC's for secondary treatment and/or nitrification, resulting in less costly upgradings.

Chemical feed or elevation of pH levels to about pH 8.0 in RBC influent increases the rate of nitrification and decreases RBC surface area requirements resulting in less costly improvement and more consistent attainment of ammonia removal.

Wastewater temperature affects both secondary treatment and nitrification within the RBC process, with nitrification rates being more sensitive to low temperatures than organic removal.

RECOMMENDATIONS

Existing trickling filters should be utilized, when possible, during the upgrading of wastewater treatment plants for secondary treatment and/or nitrification by the rotating biological contactor (RBC) process.

Seasonal standards in wastewater discharges of ammonia should be encouraged because of the more costly treatment requirements for nitrification at low temperatures.

Elevated pH control should be practiced to maintain pH levels above pH 7.0 at all times and at higher pH values during winter months to achieve less costly upgrades for biological ammonia removal (nitrification) and to more consistently meet ammonia effluent limitations.

Further research should be conducted on the proper chemical, dosage and point of addition within the RBC process, which may be optimum for nitrification.

Biological recarbonation within the RBC process should be studied in more detail to evaluate the potential of a treatment scheme consisting of the low-lime process for phosphorus removal followed by the RBC process for recarbonation and secondary treatment and/or nitrification.

LIST OF ABBREVIATIONS

NPDES	National Pollutant Discharge Elimination System
AWT	advanced wastewater treatment
BOD	biochemical oxygen demand
SS	suspended solids
NH_3-N	ammonia-nitrogen
N	nitrogen
NO_2-N + NO_3-N	nitrite-nitrogen and nitrate nitrogen
TKN	total Kjeldahl nitrogen
COD	chemical oxygen demand
TOC	total organic carbon
mg/l	milligram per liter
INF	influent
EFF	effluent
NA	not applicable
ND	no data
1°	primary
2°	secondary
TF	trickling filter
RBC	rotating biological contactor

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